M03-TMDL-01A

UPPER AND NORTH FORK BIG HOLE RIVER PLANNING AREA TMDLS AND FRAMEWORK WATER QUALITY RESTORATION APPROACH

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Montana Department of
ENVIRONMENTAL QUALITY

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ERRATA SHEET FOR THE "UPPER AND NORTH FORK BIG HOLE RIVER PLANNING AREA TMDLS AND FRAMEWORK WATER QUALITY RESTORATION APPROACH"

This TMDL was approved by EPA on June 30, 2009. Several copies were printed and spiral bound for distribution, or sent electronically on compact disks. The original version has a minor change that is explained and corrected on this errata sheet. If you have a bound copy, please note the correction listed below or simply print out the errata sheet and insert it in your copy of the TMDL. If you have a compact disk please add this errata sheet to your disk or download the updated version from our website.

Appropriate corrections have already been made in the downloadable version of the TMDL located on our website at: http://deq.mt.gov/wqinfo/TMDL/finalReports.mcpx

The following table contains corrections to the TMDL. The first column cites the page and paragraph where there is a text error. The second column contains the original text that was in error. The third column contains the new text that has been corrected for the "Upper and North Fork Big Hole River Planning Area TMDLs and Framework Water Quality Restoration Approach" document. The text in error and the correct text are underlined.

Location in the TMDL	**Original Text**	**Corrected Text**
Page 21, Section1.1, last paragraph	A total of 25 TMDLs are provided in this document.	A total of 24 TMDLs are provided in this document.

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ACRONYMS

Acronym	Meaning
ABWA	Absarokee-Beartooth Wilderness Area
ACE	Acclimated Chronic Exposure
AFO	Animal Feeding Operations
AGWT	American Ground Water Trust
AML	Abandoned Mine Lands
ARM	Administrative Rules of Montana
ATV	All Terrain Vehicle
AWRA	American Water Resources Association
Ave.	Average
BAER	Burned Area Emergency Rehab
BBCTU	Big Blackfoot Chapter of Trout Unlimited
BDNF	Beaverhead-Deerlodge National Forest
BEHI	Bank Erodibility Hazard Index
BER	Board of Environmental Review
BLM	Bureau of Land Management, United States
BMP	Best Management Practice
BNF	Bitterroot National Forest
BOD	Biochemical Oxygen Demand
BOR	Bureau of Reclamation
BP	Before Present
BUD	Beneficial Use Determination
CAFO	Concentrated Animal Feeding Operation
CALA	Controlled Allocation of Liability Act
CARRD	DNRC Conservation and Resource Development Division
CBM	Coal bed methane
CCAA	candidate conservation agreements with assurances
CCAC	Climate Change Advisory Group
CD	Conservation District
CECRA	Comprehensive Environmental Cleanup and Responsibility Act
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
CFR	Code of Federal Regulations
cfs	Cubic Feet Per Second
CH4	Methane
Chl-a	Chlorophyll A
Cl	chloride
CMB	Chemical Mass Balance
CMZ	Channel Migration Zone
CNMP	Comprehensive Nutrient Management Plans
CO2	Carbon Dioxide
CPUE	catch-per-unit-efforts
CREP	Conservation Reserve Enhancement Program
CRP	Color Removal Plant or Conservation Reserve Program
CTM	Critical Thermal Maxima (CTM)

CV .... Coefficient of variation
CWA .... Clean Water Act
DEM .... Digital Elevation Models
DEQ .... Department of Environmental Quality, Montana
DEQ-7 .... Circular DEQ-7, Montana Water Quality Standards
DHES .... Department of Health and Environmental Sciences
DMR .... Discharge Monitoring Report
DNRC .... Department of Natural Resources and Conservation
DO .... Dissolved Oxygen
DOC .... Dissolved Organic Carbon
DPHHS .... Department of Public Health and Human Services
E&O .... Education and Outreach
EC .... Electrical Conductance
ECA .... Equivalent Clear-Cut Area
EE/CA .... Engineering Evaluation/Cost Analysis
EIS .... Environmental Impact Statement
EMAP .... Environmental Monitoring and Assessment Program
EPT .... Ephmeroptera, Plecoptera, Trichoptera
EQIP .... Environmental Quality Initiatives Program
ESA .... Endangered Species Act
FAR .... Functioning at Acceptable Risk
FAS .... Federation of American Scientists
FSA .... Farm Service Agency
FUR .... Functioning at Unacceptable Risk
FWP .... Fish Wildlife and Parks, Montana Department of
FWS .... Fish and Wildlife Service
GAP .... USGS GAP Analysis Program
GHG .... Greenhouse Gases
GIS .... Geographic Information Systems
GPS .... Global Positioning Systems
GWIC .... Montana Groundwater Information Center
HBI .... Hilsenhoff Biotic Index
HCFC .... Halogenated Fluorocarbons
HCP .... Habitat Conservation Program
HFC .... Hydrofluorocarbons
HRUs .... Hydrologic Response Units
HUC .... Hydrologic Unit Code
IBI .... Index of Biological Integrity
ILT .... Incipient Lethal Temperatures
INFS .... Inland Native Fish Strategy
INFISH .... Inland Native Fish Strategy
IPCC .... Intergovernmental Panel on Climate Change
IR .... Integrated Report
ITEEM .... Integrated Transportation and Ecosystem Enhancements for Montana
ITL .... instantaneous temperature load
IWM .... Irrigation Water Management

JCU ....Jackson Candle Units
LA .... Load Allocation
LC ....Loading Capacity
LEED .... Leadership in Energy and Environmental Design
LEP ....Let Everyone Participate
LID..Low Impact Development
LNF .... Lolo National Forest
LTA...Land Type Associations
LTAP...Local Technical Assistance Program
LWD ....Large Woody Debris
MBMG..Montana Bureau of Mines and Geology
MCA ....Montana Code Annotated
MCL ....maximum contaminant level
MDEQ.. Montana Department of Environmental Quality
MDFWP.. Montana Department of Fish, Wildlife and Parks
MDOT..Montana Department of Transportation
MDSL .... Montana Department of State Lands
MDT...Montana Department of Transportation
MFISH ....Montana Fisheries Information System
mg/L..Micrograms Per Liter
mg/L...Milligrams Per Liter
mg/m2 ....milligram per meter squared
MGD ....Million Gallons per Day
MGWPCS ....Montana Ground Water Pollution Control System
MLR..Meander Length Ratio
MMI..Multi-Metric Index
MOS..Margin of Safety
MOU ....Memorandum of Understanding
MPDES ....Montana Pollutant Discharge Elimination System
mS/cm ....Microsiemens Per Liter
MSCA ....Montana Salinity Control Association
MSEO ....Montana State Engineer.s Office
MSU...Montana State University
MTNHP...Montana Natural Heritage Program
MVFP..Montana Valley and Foothill Prairie
MWCB..Mine Wast Clean Up Bureau
MWCC...Montana Watershed Coordination Council
N2O..nitrous oxide
N..Nitrogen
Na ....sodium
NDOC ....Nondissolved Organic Carbon
NEPA ....National Environmental Policy Act
NF ....National Forest
NFHCP...Native Fish Habitat Conservation Plan
NFHCP...Native Fish Habitat Conservation Plan
NHD ....National Hydrography Dataset

NO3+NO2 .... Nitrate + Nitrite as Nitrogen
NOx .... Nitrogen Oxides
NOAA .... National Oceanic and Atmospheric Administration
NPDES .... National Pollutant Discharge Elimination System
NPL .... National Priority List
NPS .... Nonpoint Source Pollution
NRCS .... Natural Resource Conservation Service
NRIS .... Natural Resource Information Services
NSF .... National Science Foundation
NTU .... Nephelometric Turbidity Units
NWIS .... National Water Information System
O3 .... ozone
O/C .... Observed/Expected
ODEQ .... Oregon Department of Environmental Quality
O/E .... Observed/Expected
OHV .... Off Highway Vehicle
P .... Phosphorus
PCB .... Polychlorinated Biphenyls
PCS .... Permit Compliance System
PCTC .... Plum Creek Timber Company
PEL .... Probable Effect Levels
PFC .... Proper Functioning Condition (Riparian)
PFI .... Peak Flow Increases
PIBO .... PACFIS/INFISH Biological Opinion
POC .... Particulate Organic Carbon
POTW .... Publicly Owned Treatment Works
PWS .... Public Water Supply
QA/QC .... Quality Assurance and Quality Control
RBP .... Rapid Bioassessment Protocol
RIVPACS .... River Invertebrate Prediction and Classification System
RMO .... Riparian Management Objectives
ROS .... Rain-on-Snow
RSI .... Rifle Stability Index
SABS .... Suspended and Bedded Sediments
SAP .... Sampling and Analysis Plans
SAR .... Sodium Adsorption Ratio
SC .... Specific Conductance
SCD .... Sufficient Credible Data
SCD/BUD .... Sufficient and Credible Data/Beneficial Use Determination
SCORP .... Statewide Comprehensive Outdoor Recreation Plan
SDWIS .... Safe Drinking Water Information System
SD .... Secci Depth
SDDENR .... South Dakota Department of Environment and Natural Resources
SEL .... Severe Effects Level
SEV .... Severity of ill Effects
SMCRA .... Surface Mining Control and Reclamation Act

SMZ .... Streamside Management Zones
SNTEMP .... Stream Network Temperature
SNOTEL .... Snowpack Telemetry
SO4 .... sulfate
SRF .... State Revolving Fund
SRP .... Soluble Reactive Phosphorus
SS .... Suspended Sediment
SSTEMP .... Stream Segment Temperature
STATSGO .... State Soil Geographic Database
STORET .... EPA's Storage/Retrieval Database
SSURGO .... Soil Survey Geographic Database
SWCS .... Soil and Water Conservation Society
SWMP .... Storm Water Management Program
TAG .... Technical Advisory Group
TDS .... Total dissolved solids
TEL .... Threshold Effect Levels
TET .... Toxic Effect Threshold
TFAB .... Technical and Financial Assistance Bureau
TIN .... Total Inorganic Nitrogen
TIP .... Total Inorganic Phosphorus
TKN .... Total Kjeldahl Nitrogen
TMDL .... Total Maximum Daily Loads
TMI .... Total Metals Index
TN .... Total Nitrogen
TP .... Total Phosphorus
TPA .... TMDL Planning Area
TPN .... Total Persulfate Nitrogen
TR .... Total Recoverable
TRWG .... Teton River Watershed Group
TRWU .... Tongue River Water Users
TSCA .... Toxic Substances Control Act
TSI .... Trophic State Index
TSS .... Total Suspended Solids
UAA .... Use Attainability Assessment
UET .... Upper Effect Threshold
UNESCO .... United Nations Educational, Scientific and Cultural Organization
USCOE .... United States Army Corp of Engineers
USDA .... United State Department of Agriculture
USDI .... United States Department of Interior
USEPA .... United States Environmental Protection Agency
USFS .... United States Forest Service
USFWS .... United States Fish and Wildlife Service
USGBC .... United States Green Building Council
USGS .... United States Geological Survey
USLE .... Universal Soil Loss Equation
VCRA .... Voluntary Cleanup and Redevelopment Act

VFS .... Vegetated Filter Strips
VNRP .... Voluntary Nutrient Reduction Program
VNRS .... Voluntary Nutrient Reduction Strategy
W/D Ratio .... Width to Depth Ratio
WEPP .... Water Erosion Prediction Project
WQA .... Water Quality Act
WLA .... Waste Load Allocation
WQMWG .... Water Quality Monitoring Work Group
WQPB .... Water Quality Planning Bureau
WQRP .... Water Quality Restoration Plan
WQS .... Water Quality Standards
WRCC .... Western Regional Climate Center
WRP .... Watershed Restoration Plans
WTI .... Western Transportation Institute
WWTP .... Waste Water Treatment Plant
YBP .... Yellowstone Business Partnerships
YOY .... Young of Year
μg/g .... microgram per gram

EXECUTIVE SUMMARY

This document presents Total Maximum Daily Loads (TMDLs) and framework water quality improvement plans for the Upper and North Fork Big Hole River and 18 impaired tributaries (**Appendix K**, **Map 1**). This plan was developed by the Montana Department of Environmental Quality (DEQ) and submitted to the US Environmental Protection Agency (EPA) for approval, in accordance with the Montana Water Quality Act. The 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 water body can receive and still meet water quality standards. The goal of TMDLs is to eventually attain and maintain water quality standards in all of Montana's streams and lakes, and to improve water quality to levels that support all state-designated beneficial water uses.

The Upper and North Fork Big Hole TMDL Planning Areas (TPAs) are located in Beaverhead County and include the Big Hole River and its tributaries from headwaters to the confluence with Doolittle Creek. The tributaries originate in the Pintler, Pioneer and Beaverhead Mountains. The watershed drainage area encompasses about 730,800 acres, with land ownership consisting of federal, state, and private lands.

DEQ has performed assessments determining that the Big Hole River above Doolittle Creek and its 18 tributaries do not meet the applicable water quality standards. The scope of the TMDLs in this document address sediment, temperature and nutrient related problems (See **Table E-1**). Metals were assessed in a number of watersheds but no metals TMDL is provided in the document. Additional TMDLs in this TPA may be required in the future and a number of these circumstances are noted within the document.

<u>Sediment</u> – Sediment TMDLs were developed for the Big Hole River, North Fork Big Hole River, Doolittle, Fox, Francis, Governor, Johnson, Joseph, McVey, Miner, Mussigbrod, Pine, Rock, Ruby, Steel, Swamp, Tie, and Trail Creeks. Sediment is impacting beneficial water uses in these streams by smothering aquatic insect habitat, reducing fish spawning success, or filling pools which reduces fish populations. Water quality restoration endpoints for sediment in these stream segments were established for fine sediment levels in trout spawning areas, fine sediment in riffles where many aquatic insects reside, number of pools within a reach of stream, riparian vegetation health and the stability of streambanks. Attainment of these endpoints is believed to be capable of restoring all water uses presently impacted by sediment.

Sediment loads were quantified for naturally occurring conditions and impacted conditions for the following sources: bank erosion, hillslope erosion, and roads. The most significant sources included natural sediment loads, agricultural related loads from riparian vegetation impacts that influence bank erosion, and unpaved roads. The sediment TMDLs completed in the Upper and North Fork Big Hole TPAs indicate that reductions in sediment loads ranging from 10% to 46% will result in meeting the water quality restoration endpoints depending upon the watershed.

<u>Nutrients</u> – Francis and Steel Creeks were identified for nutrient TMDL formation. Nutrient targets include total nitrogen, total phosphorus, algae related measures and dissolved oxygen. Nutrient TMDLs are based upon target concentrations and stream flow. Nutrient allocations are

based upon water quality modeling results of specific restoration scenarios. Rock, McVey, Swamp, Fox, Pine and Warm Spring Creek watersheds may need nutrient TMDLs in the future. Many of these streams were added to Montana's list of impaired waters as nutrient limited during this TMDL development project. Other nutrient limited watersheds contained complex irrigation systems which imported and exported nutrients into and out of the watershed. Nutrient TMDLs could not be completed in these heavily influenced watersheds given current knowledge.

Metals – Various metals were assessed in Steel, Governor, Mussigbrod, and Joseph Creeks. No metals TMDLs are provided in this document because of varying reasons within each of these watersheds. Either human sources were not present when metals were found or metals were not found above targets during recent sampling if mining sources were present.

Water Temperature – A temperature TMDL is provided for the Upper Big Hole River above Doolittle Creek Confluence. The recommended strategies for achieving the pollutant reduction goals of the Upper and North Fork Watershed TMDLs are also presented in this plan. The most significant pollutant reductions will come from restoration of natural shrubby riparian buffers in the Upper Big Hole Valley. Healthy riparian zones will filter sediment and nutrients from runoff and update nutrients from groundwater before it enters streams. Promoting healthy riparian vegetation will also slow bank erosion and increase shade over streams. Many riparian areas will benefit from passive restoration approaches but some will need active riparian restoration. Creating more healthy riparian vegetation can be provided in the Upper Big Hole Valley by grazing management techniques and moving hay production away from immediate streamside areas.

Other recommended approaches, which will reduce pollutants, are unpaved road management, timber harvest practices that do not increase erosion to stream networks, road sanding BMPs, and the use of other land, soil and water conservation practices *capable of improving condition of stream channels and associated riparian vegetation.*

Implementation of most water quality improvement measures described in this plan is based on voluntary actions of watershed stakeholders. Ideally, the TMDL and associated information within this document will be used by a local watershed group and/or other watershed stakeholders as a tool to help guide and prioritize local water quality improvement activities. These improvement activities can be documented within a watershed restoration plan consistent with DEQ and EPA recommendations.

It is recognized that a flexible and adaptive approach to most TMDL implementation activities may become necessary as more knowledge is gained through implementation and future monitoring. The plan includes an effectiveness monitoring strategy that is designed to track future progress towards meeting TMDL objectives and goals, and to help refine the plan during its implementation.

Table E-1: List of Water Bodies, Impairment Causes, and Impaired Uses in the Upper and North Fork Big Hole TPAs for Which TMDLs Were Completed

Water Body & Location Description	Impairment Cause	TMDL Pollutant Category Completed
Big Hole River, above Pintlar Creek	Temperature	Temperature
North Fork Big Hole River, headwaters to mouth (Big Hole River)	Sediment/siltation	Sediment
Johnson Creek, headwaters to mouth (North Fork Big Hole River)	Sediment/siltation	Sediment
Tie Creek, headwaters to mouth (North Fork Big Hole River)	Sediment/siltation	Sediment
Trail Creek, Headwaters to Joseph Creek	Sediment/siltation	Sediment
Trail Creek, Joseph Creek to mouth (North Fork Big Hole River)	Sediment/siltation	Sediment
Joseph Creek, headwaters to mouth (Trail Creek-North Fork Big Hole River)	Sediment/siltation	Sediment
Ruby Creek, headwaters to mouth (North Fork Big Hole River)	Sediment/siltation	Sediment
Swamp Creek, headwaters to mouth (Big Hole River)	Sediment/siltation	Sediment
Rock Creek, headwaters to mouth (Big Hole River)	Sediment/siltation	Sediment
Miner Creek, headwaters to mouth (Big Hole River)	Sediment/siltation	Sediment
Steel Creek, headwaters to mouth (Big Hole River)	Phosphorus	Nutrients
Francis Creek, headwaters to mouth (Steel Creek) T3S R15W	Phosphorus Nitrogen Sediment/siltation	Nutrients Sediment
McVey Creek, headwaters to mouth (Big Hole River) T1S R15W	Sediment/siltation	Sediment
Doolittle Creek, tributary to the Big Hole River T1S, R14W	Sediment/siltation	Sediment

New data collected during this project indicated the need for sediment TMDLs in six other watersheds in addition to the TMDLs identified as needed by Montana's impaired waters list. The additional TMDLs completed within this document address aquatic life and cold water fishery impacts of siltation in the Upper Big Hole River, Fox, Governor, Mussigbrod, Pine and Steel creeks. Also, a nitrogen TMDL has been provided for Steel Creek.

SECTION 1.0
INTRODUCTION

1.1 Background

This document, the Upper Big Hole River Planning Area TMDLs and Framework Water Quality Restoration Approach, describes the Montana Department of Environmental Quality's present understanding of sediment, nutrient and temperature water quality problems in rivers and streams of the Upper and North Fork Big Hole River TPAs and presents a general framework for resolving them. **Appendix K, Map 1** identifies the water bodies discussed within this document.

Congress passed the Water Pollution Control Act, more commonly known as the Clean Water Act, in 1972. The goal of this act is to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters." The Clean Water Act requires each state to set water quality standards to protect designated beneficial water uses and to monitor the attainment of those uses. Fish and aquatic life, wildlife, recreation, agriculture, industrial, and drinking water are all types of beneficial uses designated in Montana. Streams and lakes (also referred to as water bodies) not meeting the established standards are called *impaired waters*, and those not expected to meet the standards are called *threatened waters*.

The water bodies with their associated impairment and threatened causes are identified within a biennial integrated water quality report developed by DEQ (**Table 1-1** identifies impaired waters for the Upper and North Fork Big Hole River TPAs). Impairment causes fall within two main categories: pollutant and pollution. Both Montana state law (Section 75-5-701 of the Montana Water Quality Act) and section 303(d) of the federal Clean Water Act require the development of total maximum daily loads (TMDLs) for impaired and threatened waters where a measurable pollutant (for example, sediment, nutrients, metals or temperature) is the cause of the impairment. The water body segments with pollutant impairment causes in need of TMDL development are contained within the 303(d) List portion of the State's integrated water quality report. The integrated report identifies impaired waters by a Montana water body segment identification, which is indexed to the National Hydrography Dataset.

A TMDL refers to the maximum amount of a pollutant a stream or lake can receive and still meet water quality standards. The development of TMDLs and water quality improvement strategies in Montana includes several steps that must be completed for each impaired or threatened water body and for each contributing pollutant (or "pollutant/water body combination"). These steps include:

- Characterizing the existing water body conditions and comparing these conditions to water quality standards. During this step, measurable target values are set to help evaluate the stream's condition in relation to the applicable standards.
- Quantifying the magnitude of pollutant contribution from the pollutant sources
- Determining the TMDL for each pollutant, based on the allowable loading limits (or loading capacity) for each pollutant/water body combination.
- Allocating the total allowable load (TMDL) into individual loads for each source (referred to as the load allocations or waste load allocations).

In Montana, restoration strategies and recommendations are also incorporated in TMDL documents to help facilitate TMDL implementation.

The above four TMDL steps are further defined in Section 4.0 of this document. Basically, TMDL development for an impaired water body is a problem solving exercise. The problem is excess pollutant loading negatively impacting a designated beneficial use. The solution is developed by identifying the total acceptable pollutant load to the water body (the TMDL), characterizing all the significant sources contributing to the total pollutant loading, and then identifying where pollutant loading reductions should be applied to one or more sources to achieve the acceptable load.

Table 1-1: 2006 Impaired Water Bodies, Impairment Causes, and Impaired Beneficial Uses in the Upper and North Fork Big Hole River TPAs.

Water body & Location Description	Water body ID	Impairment Cause	TMDL Pollutant Category	Impaired Uses
Big Hole River, above Pintlar Creek	MT41D001-030	Habitat Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery
		Temperature	**Temperature***	Aquatic Life, Cold Water Fishery
		Low Flow Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery, Recreation
North Fork Big Hole River, headwaters to mouth (Big Hole River)	MT41D004-010	Habitat Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery
		Sedimentation/ Siltation	**Sediment**	Aquatic Life, Cold Water Fishery
		Low Flow Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery, Recreation
Mussigbrod Creek, headwaters to mouth (North Fork Big Hole River)	MT41D004-020	Habitat Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery
		Lead	Metals	Aquatic Life, Cold Water Fishery
		Low Flow Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery, Recreation
Johnson Creek, headwaters to mouth (North Fork Big Hole River)	MT41D004-030	Habitat Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery
		Sedimentation/ Siltation	**Sediment**	Aquatic Life, Cold Water Fishery
		Low Flow Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery, Recreation
		Total Kjehldahl Nitrogen (TKN)	Nutrients	Aquatic Life, Cold Water Fishery
Schultz Creek, headwaters to mouth (Johnson Creek)	MT41D004-040	Sedimentation/ Siltation	Sediment	Aquatic Life, Cold Water Fishery

Table 1-1: 2006 Impaired Water Bodies, Impairment Causes, and Impaired Beneficial Uses in the Upper and North Fork Big Hole River TPAs.

Water body & Location Description	Water body ID	Impairment Cause	TMDL Pollutant Category	Impaired Uses
Tie Creek, headwaters to mouth (North Fork Big Hole River)	MT41D004-060	Habitat Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery
		Sedimentation/ Siltation	**Sediment**	Aquatic Life, Cold Water Fishery
		Nitrogen	Nutrients	Aquatic Life, Cold Water Fishery
Trail Creek, headwaters to Joseph Creek	MT41D004-070	Habitat Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery
		Sedimentation/ Siltation	**Sediment**	Aquatic Life, Cold Water Fishery
Trail Creek, Joseph Creek to mouth (North Fork Big Hole River)	MT41D004-080	Habitat Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery
		Sedimentation/ Siltation	**Sediment**	Aquatic Life, Cold Water Fishery
Joseph Creek, headwaters to mouth (Trail Creek-North Fork Big Hole River)	MT41D004-090	Habitat Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery
		Sedimentation/ Siltation	**Sediment**	Aquatic Life, Cold Water Fishery
		Lead	Metals	Aquatic Life, Cold Water Fishery, Drinking Water
		Copper	Metals	Aquatic Life, Cold Water Fishery
Ruby Creek, headwaters to mouth (North Fork Big Hole River)	MT41D004-100	Habitat Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery
		Sedimentation/ Siltation	**Sediment**	Aquatic Life, Cold Water Fishery
		Low Flow Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery, Recreation
Swamp Creek, headwaters to mouth (Big Hole River)	MT41D004-110	Habitat Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery
		Sedimentation/ Siltation	**Sediment**	Aquatic Life, Cold Water Fishery
		Low Flow Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery, Recreation
		Nitrogen	Nutrients	Aquatic Life, Cold Water Fishery
		Phosphorus	Nutrients	Aquatic Life, Cold Water Fishery

Table 1-1: 2006 Impaired Water Bodies, Impairment Causes, and Impaired Beneficial Uses in the Upper and North Fork Big Hole River TPAs.

Water body & Location Description	Water body ID	Impairment Cause	TMDL Pollutant Category	Impaired Uses
Rock Creek, headwaters to mouth (Big Hole River)	MT41D004-120	Habitat Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery
		Sedimentation/ Siltation	**Sediment**	Aquatic Life, Cold Water Fishery
		Low Flow Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery, Recreation
		Nitrogen	Nutrients	Aquatic Life, Cold Water Fishery
		Phosphorus	Nutrients	Aquatic Life, Cold Water Fishery
Miner Creek, headwaters to mouth (Big Hole River)	MT41D004-140	Sedimentation/ Siltation	**Sediment**	Aquatic Life, Cold Water Fishery
Governor Creek, headwaters to mouth (Big Hole River-South of Jackson)	MT41D004-150	Habitat Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery
		Low Flow Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery, Recreation
		Copper	Metals	Aquatic Life, Cold Water Fishery
Pine Creek, headwaters to mouth (Andrus Creek-Governor Creek)	MT41D004-160	Habitat Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery
		Phosphorus	Nutrients	Aquatic Life, Cold Water Fishery
Fox Creek, headwaters to mouth (Governor Creek)	MT41D004-170	Phosphorus	Nutrients	Aquatic Life, Cold Water Fishery
Warm Springs Creek, headwaters to mouth (Big Hole River-Near Jackson)	MT41D004-180	Habitat Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery
		Sedimentation/ Siltation	Sediment	Aquatic Life, Cold Water Fishery
		Low Flow Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery, Recreation
		Total Kjehldahl Nitrogen (TKN)	Nutrients	Aquatic Life, Cold Water Fishery
		Phosphorus	Nutrients	Aquatic Life, Cold Water Fishery
Steel Creek, headwaters to mouth (Big Hole River)	MT41D004-190	Habitat Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery
		Low Flow Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery, Recreation
		Copper	Metals	Aquatic Life, Cold Water Fishery
		Cadmium	Metals	Aquatic Life, Cold Water Fishery
		Phosphorus	**Nutrients**	Aquatic Life, Cold Water Fishery

Table 1-1: 2006 Impaired Water Bodies, Impairment Causes, and Impaired Beneficial Uses in the Upper and North Fork Big Hole River TPAs.

Water body & Location Description	Water body ID	Impairment Cause	TMDL Pollutant Category	Impaired Uses
Francis Creek, headwaters to mouth (Steel Creek) T3S R15W	MT41D004-200	Habitat Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery
		Nitrogen	**Nutrients**	Aquatic Life, Cold Water Fishery
		Phosphorus	**Nutrients**	Aquatic Life, Cold Water Fishery
		Sedimentation/ Siltation	**Sediment**	Aquatic Life, Cold Water Fishery
McVey Creek, headwaters to mouth (Big Hole River) T1S R15W	MT41D004-210	Habitat Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery
		Nitrogen	Nutrients	Aquatic Life, Cold Water Fishery
		Phosphorus	Nutrients	Aquatic Life, Cold Water Fishery
		Sedimentation/ Siltation	**Sediment**	Aquatic Life, Cold Water Fishery
Doolittle Creek, tributary to the Big Hole River T1S, R14W	MT41D004-220	Habitat Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery
		Sedimentation/ Siltation	**Sediment**	Aquatic Life, Cold Water Fishery
		Low Flow Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery, Recreation
Pintlar Creek, headwaters to mouth (Big Hole River)	MT41D003-170	Habitat Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery
		Temperature	Temperature	Aquatic Life, Cold Water Fishery
		Low Flow Alterations	Not a Pollutant	Aquatic Life, Cold Water Fishery, Recreation

*Bold text in the pollutant category column indicates a TMDL is included for the pollutant in this document.

This document only provides TMDLs for pollutants identified by bold text in **Table 1-1**. The TMDLs address the associated impairment causes. New data collected during this project indicated the need for sediment TMDLs in six other watersheds in addition to the TMDLs identified as needed by Montana's impaired waters list. The additional TMDLs completed within this document address aquatic life and cold water fishery impacts of siltation/sedimentation in the upper Big Hole River, Fox, Governor, Mussigbrod, Pine, and Steel creeks. Also a nitrogen TMDL was completed for Steel Creek which Montana's impaired waters list did not identify. A total of 24 TMDLs are provided in this document. Other impairment causes in **Table 1-1** will be addressed in the future.

1.2 Water Quality Impairments and TMDLs Addressed Within This Plan

Water quality impairments affecting the Upper Big Hole River and its tributaries, which are addressed by this plan, include sediment, nutrients, metals, and elevated water temperatures. These pollutants have been shown to impair some designated uses of these streams, including aquatic life and cold water fisheries, and drinking water (See **Table 1-1**). Because TMDLs are completed for each pollutant/water body combination, this framework water quality improvement plan, contains several TMDLs.

The DEQ recognizes there are some pollutant listings for this TPA that are not addressed with TMDLs at this time, however, some pollutants may not have been on Montana's list of impaired waters at the time this TMDL project was initiated. Other TMDLs may not have been addressed at this time because there may have been unacceptable levels of uncertainty with current knowledge or because there were indications in newly collected data that a number of the TMDLs were not necessary even though pollutants were identified as potentially influencing a use on Montana's impaired waters list.

Impairment can be due to a group of causes defined as "pollution". TMDLs are not required for pollution, 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 pollutant problems. The link between pollutant TMDLs in this document and pollution impairment causes usually resides in the source assessment of pollutants and the restorataion strategy to reduce pollutant loads. For instance, most sediment sources within the watershed relate to riparian vegetation conditions that hold soils in the streambanks together and provide sediment filtering near streams. Riparian habitat alterations are a source of sediment in many areas of this watershed and are addressed by sediment TMDLs in the restoration approach for reducing sediment load to the stream network. Similarly, the temperature TMDL for the Big Hole River addresses reduced flows as a source of heating in the source assessment. Flow alteration is not a pollutant, yet it influences stream temperature. Restoration approaches for the temperature TMDL identify stream flow as an important approach to reducing temperature.

1.3 Stakeholder and Public Participation

A technical advisory approach was used during the TMDL process. During the initial phases of TMDL development technical advisors and local stakeholders were provided the opportunity to supply information about known pollutant sources in the watershed and give comment on monitoring and modeling approaches for TMDL development. The Big Hole Watershed Committee and Big Hole River Foundation provided support for TMDL monitoring in a number of ways. Both groups supplied labor resources for TMDL monitoring crews. The Big Hole Watershed Committee provided landowner outreach during this timeframe to educate landowners about the TMDL process while securing land access for monitoring. These groups also provided in-kind local effort and secured state funding match to provide the State of Montana an avenue for use of federal funding for this project. The United States Forest Service also assisted in sediment, riparian habitat, temperature, metals and nutrient monitoring. Montana MDT completed a road sanding study for Lost Trail Pass for use in the TMDL effort.

Stakeholder and public comment processes considerations are reviewed in more detail in **Section 12.0** of this document.

1.4 Document Layout

The main body of the document provides a summary of the TMDL components. Additional technical details of these components are contained in the appendices of this report. In addition to this introductory section which includes the background, identification of TMDLs developed, and a description of stakeholder involvement during TMDL development, this document has been organized into the following sections:

- **Section 2.0 –**Watershed Description: a description of the physical and social characteristics of the watershed.
- **Section 3.0 –** Montana Water Quality Standards: discusses the water quality standards that apply to the watershed.
- **Section 4.0 –** Description of water quality target conditions and influencing factors.
- **Section 5.0 –** Comparison of existing conditions for each stream of interest and how they compare to the water quality targets and influencing factors.
- **Section 6.0 –** Description of TMDL necessary components.
- **Sections 7.0-9.0 –** Sediment, Nutrient, and Temperature TMDL Components, sequentially: each section summarizes identified sources of the respective pollutant and the determined TMDL for the respective pollutant / water body combinations addressed by this plan.
- **Section 10.0 –** Restoration Objectives and Implementation Plan: discusses water quality restoration objectives and presents a framework implementation strategy for meeting the identified objectives and TMDLs.
- **Section 11.0 –** Monitoring for Effectiveness: describes a water quality monitoring plan for addressing uncertainty in assessments and evaluation the long term conditions within the watershed
- **Section 12.0 –** A review of technical, stakeholder and public involvement activities during this TMDL process.
- **Section 13.0 –** Literature Reference

SECTION 2.0
WATERSHED CHARACTERIZATION

The Upper Big Hole River Watershed lies in the southwest corner of Montana, about 50 miles west of Dillon, Montana (**Appendix K**, **Map 1**). The Upper Big Hole River TMDL planning area (TPA) is approximately 1,200 square miles (770,761 acres) and encompasses all the area upstream from the confluence of the Big Hole River with Pintlar Creek. This section provides a description of the physical, ecological, and socioeconomic character of the Upper Big Hole River TPA. Additionally, this chapter includes discussion of the relations between watershed characteristics to TMDLs and associated conservation issues in the basin.

2.1 Geological Setting

The Upper Big Hole River Valley is one of the widest and highest elevation valleys in southwest Montana. The valley area is approximately 32 x 52 miles and the valley floor elevation exceeds 6,000 feet throughout. Much of the valley bottom consists of Quaternary alluvial and glacial deposits, often overlying Tertiary aged sedimentary rocks of the Bozeman Formation (**Map 2**). The Beaverhead Mountains along the western edge of the watershed consist mostly of Proterozoic age quartzite, argillite, limestone, and shale. The Pioneer Mountains, which consist dominantly of Cretaceous granitic intrusive rocks, comprise the eastern boundary of the watershed. The northern boundary, defined by the Anaconda Range, consists mostly of Tertiary granitic intrusive rocks. Oil exploration in the 1980s revealed thick accumulations of Tertiary sediments filling the Upper Big Hole Valley. These basin fill deposits, which approach 14,000 feet in depth, are thicker than any other in the region (Alt and Hyndman 1986).

2.2 Soils

Detailed soils data is currently unavailable for the Upper Big Hole River TPA. However, the Natural Resource Conservation Service (NRCS) is currently conducting a detailed Soil Survey Geographic Database (SSURGO) soils survey and those data should be available for future efforts. Evaluation of the SSURGO soils database for Madison County indicates that soils contributed from the Bozeman Formation typically have low available water capacity, low clay content, and high permeability. This suggests that these soils have insufficient capacity to hold adequate water to support substantial plant growth. The nature of soils has implications for water management and TMDL planning in the basin.

2.3 Climate

The climate of the basin is an important consideration in support of sensitive beneficial uses. Long, cold winters and short, moderately hot and dry summers characterize the climate of the Upper Big Hole River Watershed. Average monthly minimum temperatures and maximum temperatures range from 1.8-78.1°F in January and July, respectively. The valley portions of the watershed are semiarid with average annual precipitation of 11.82 inches/year at Wisdom. Headwater portions of the watershed receive considerably more precipitation, reaching an average 53 inches/year in the headwaters of Berry Creek, located in the southwest portion of the watershed. The growing season is short, with an average of 45 frost-free days/year. Maximum daily temperatures are below freezing for an average of 75 days/year. A precipitation map can be found in **Appendix A**.

2.4 Hydrology

The hydrology of the Upper Big Hole River and its tributaries reflect significant alteration of natural flows due to water use practices. Because dewatering and associated thermal impairments figure largely in many of the 303(d) Listed streams, a detailed description of groundwater and surface water hydrology provides useful information to support TMDL planning. This section describes hydrologic conditions in the Upper Big Hole River Watershed based on existing hydrologic studies and limited evaluation of more recent gage data.

2.4.1 Surface Water Hydrology

Readily available stream gage data document the magnitude, timing and patterns of stream flow in the Upper Big Hole River TPA. Mean daily stream flows measured at three USGS gaging stations (**Table 2-1**) provide the basis to describe the surface water hydrology of the mainstem Big Hole River. The stream gage located in the uppermost watershed area (Big Hole River near Jackson gage) lies near Van Houten Lake. This gage station was active from 1948-1953. The gage located at Wisdom has been active since 1988 and has mean daily flow data for the months of April through December. Located further downstream, the gage below Mudd Creek has been active since 1997, and has recorded mean daily stream flow values for the months of April through October. It is important to note that the relatively short, recent periods of record for each gage encompass only impacted hydrologic conditions. Therefore, it is impossible to use the gage data to quantify natural flows or to quantify long-term hydrologic trends. The following analyses provide a means to evaluate existing hydrographic features and draw inference regarding the effect of human activities on basin hydrology:

- Maximum mean daily flow
- Mean monthly stream flow
- Low flow duration analysis

Table 2-1: USGS gaging stations utilized in hydrologic characterization

Site Number	Site Name	Period of Record	Drainage Area (sq mi)	Months Recorded
06023500	Big Hole River near Jackson	Apr 1948-Oct 1953	44	Jan-Dec
06024450	Big Hole River below Big Lake Cr at Wisdom	May 1988-Sept 2002	575	Apr-Dec
06024540	Big Hole River below Mudd Cr nr Wisdom	Oct 1997- Sept 2002	1267	Apr-Oct

- Recorded annual peak flows identify historic patterns of flooding in the watershed. At the Wisdom gage, measured annual peak flows between 1988 and 2002 ranged from less than 500 cfs to almost 4000 cfs (**Figure 2-1**). Individual periods with relatively low annual peak flows include 1988-1990, 1992-1994, and 2000-2002. Relatively high peak flows characterized the period from 1995-1999, with flows exceeding 1500 cfs at Wisdom each of those years. On June 7, 1991, flows at the Wisdom gage peaked at 3830 cfs, which is the flood of record at the gage. Since 2000, peak discharges at the Wisdom gage have been below 1300 cfs; measured peak discharges during 2000 and 2001 at the Wisdom gage were 649 cfs and 563 cfs, respectively. Peak flows downstream at the gage near Mudd Creek are typically 2 to 2.7 times larger than flows measured at Wisdom, reflecting the increased contributing drainage area at that location, including the North Fork Big Hole River.

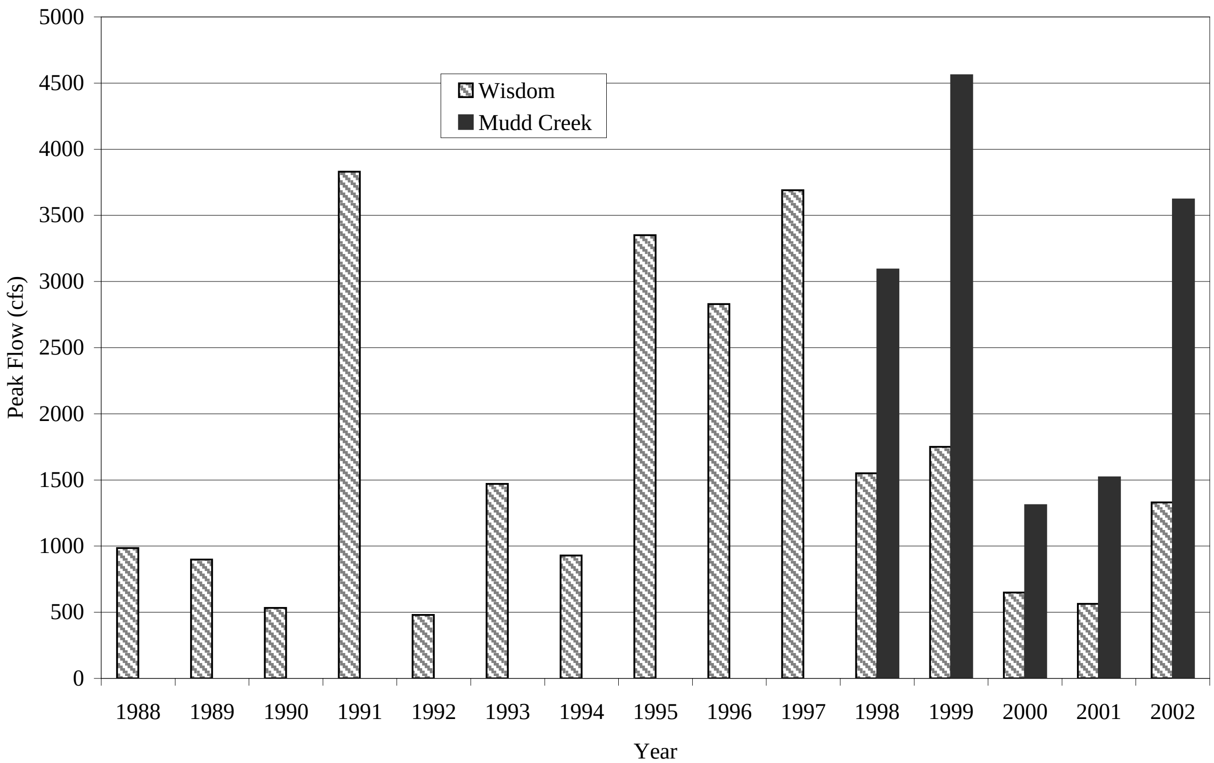

Figure 2-1: Annual peak discharges, Upper Big Hole River near Wisdom, and near Mudd Creek.

Recorded mean monthly discharge at the three gages indicate that annual peak water yields occur during the months of May and June on the mainstem Big Hole River, which is due to a combination of precipitation and snowmelt runoff during that time (**Figure 2-2**). Although the rising limb of the spring snowmelt hydrograph tends to be gradual through the months of April through June, flows tend to drop rapidly through late June and July, creating an asymmetric mean monthly hydrograph. This asymmetry increases in the downstream direction from Jackson to below Mudd Creek. The rapid drop in the recessional limb of the spring runoff hydrograph correlates to the onset of flood irrigation practices in the basin indicating the effect of this use on water quantity in the Big Hole River.

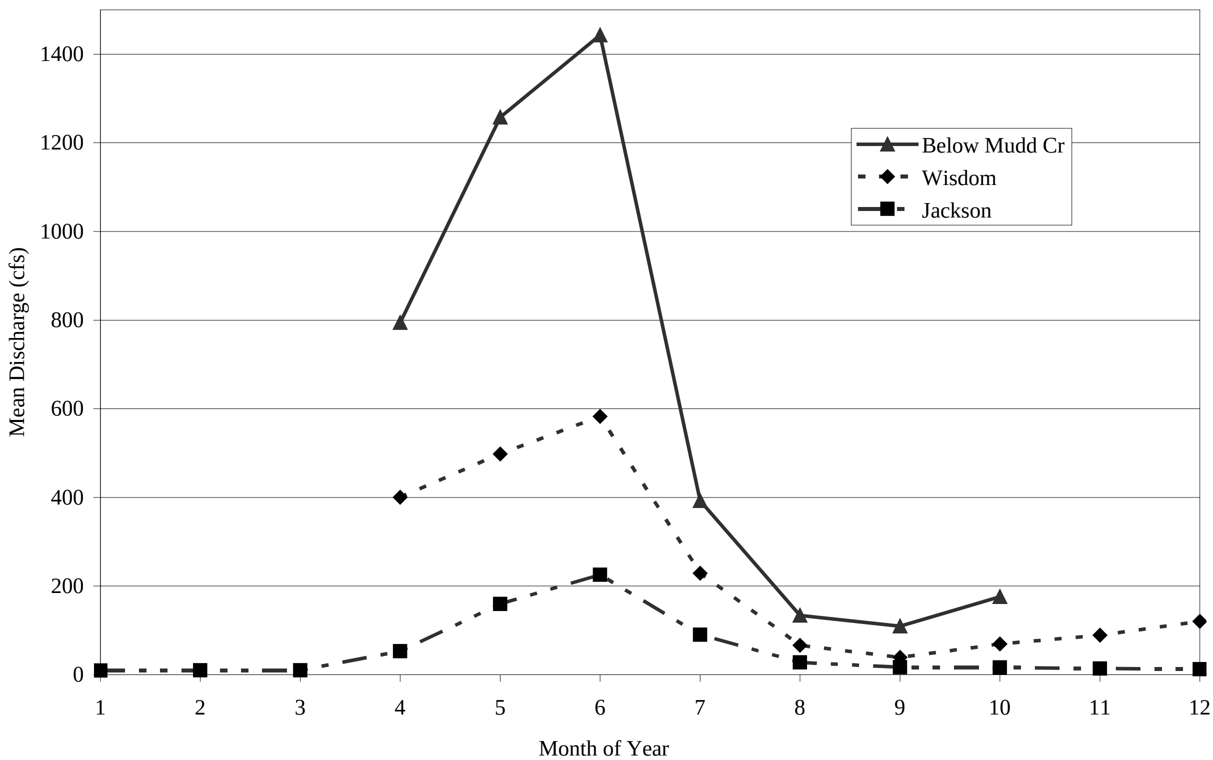

Figure 2-2: Mean monthly discharge for period of record on Upper Big Hole River USGS stream gages.

Analysis of mean daily stream flow data also describes the timing and magnitudes of minimum flows at a given location. One way to assess typical low flows is through an analysis of flow duration for a given stream gage record. Flow duration refers to the percent time that a given flow value is equaled or exceeded. A 100% duration flow reflects the flow equaled or exceeded 100% of the time, or the minimum flow value recorded at the gage. Flow duration curves for the three gaging stations illustrate effects of dewatering on the Big Hole River between the Jackson and Wisdom gaging stations, a reach providing critical habitat for Arctic grayling. Although the data from near Jackson and below Mudd Creek show 100% duration flows in excess of approximately 10 cfs, the Wisdom gage depicts a significant drop in flow magnitudes at about the 95% flow duration (**Figure 2-3**). Over the period of record at the Wisdom gage (April through December, 5/1988-9/2002), flows have been below 10 cfs approximately 5% of the time.

Seasonal dewatering of the Big Hole River is a leading cause of degraded fisheries habitat (Byorth and Magee 1996). At the Wisdom gage, a minimum discharge of 60 cfs is necessary to maintain the existing fishery, and a “minimum survival flow” of 20 cfs is required for short-term fisheries survival (DNRC 1995). At Wisdom, the proposed “minimum survival flow” of 20 cfs was unattained approximately 12% of the time over the period of record (**Figure 2-3**). The proposed fisheries maintenance discharge of 60 cfs was unattained approximately 39% of the time

In the uppermost reaches of the Big Hole River, from 1948 through 1953, which is the period of record at the gage near Jackson, flows exceeded a minimum of 9 cfs every day between April and October. Downstream at Wisdom, where the contributing drainage area is approximately 13 times larger, flows were less than 9 cfs for a total of 151 days, during the months of April through October, from 1988 to 2002 (5% of the time). This suggests that either natural runoff varied dramatically during the two periods of record, or that significant low flow dewatering occurs between the headwaters of the Big Hole River and Wisdom.

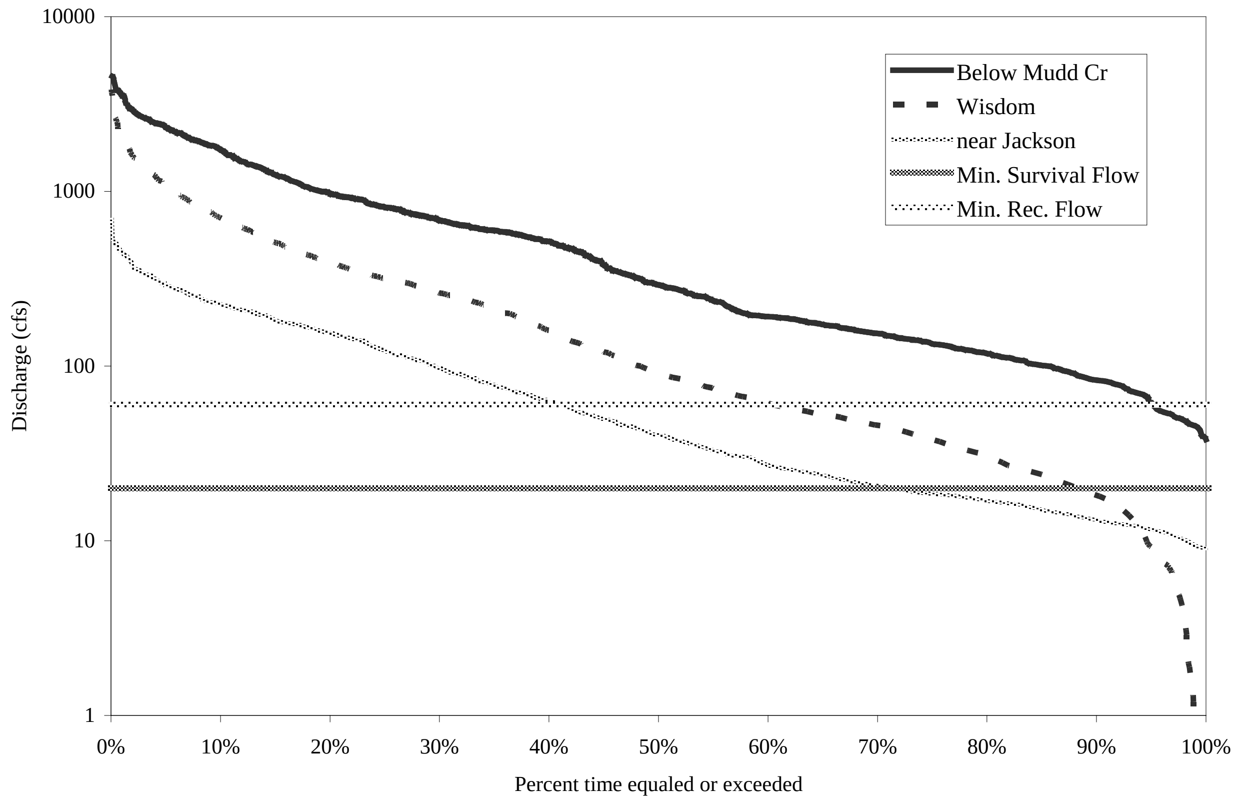

Figure 2-3: Mean daily flow duration curves for the Upper Big Hole River stream gage data, April though October.

Assessment of minimum-recorded, daily flows for the period of record clearly depicts the reduction of in stream flows in the Upper Big Hole River at Wisdom. Minimum flows tend to occur between early August and late September (**Figure 2-4**). Between late July and August, minimum flows were all less than 10 cfs. Minimum flows of less than 20 cfs have occurred in the months of June, July, August, September, and October.

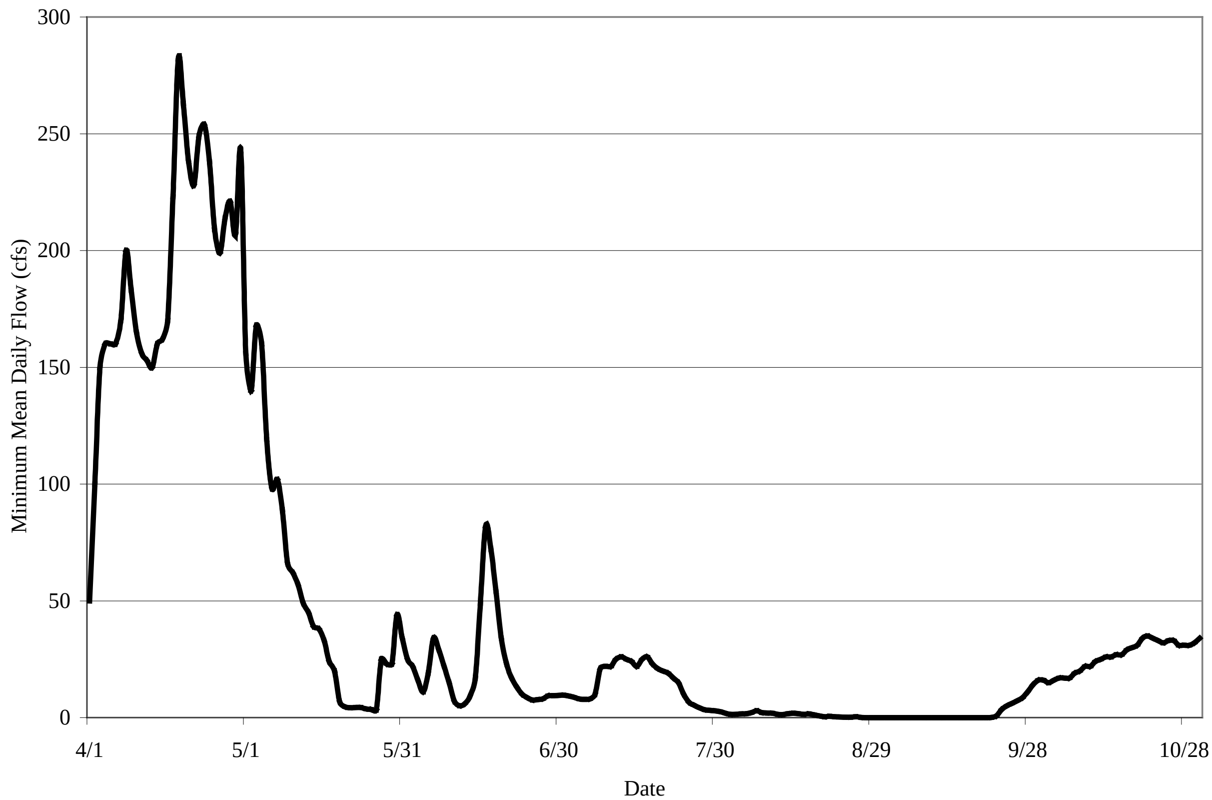

Figure 2-4: Minimum recorded mean daily discharge, 1988-2002, Big Hole River near Wisdom

A comparison of the stream flow contributed from individual major sub-watersheds identifies spatial trends in surface water withdrawals. Fundamentally, in a single basin, the relative contribution of flow from contributing sub-watersheds relates in part to the sub-watershed's drainage area. The contributing drainage area above the Wisdom gage (575 sq mi) is approximately 45% of that contributing to the gage below Mudd Creek. (1267 sq mi). The largest contributing sub-watershed between Wisdom and Mudd Creek is the North Fork Big Hole River. As the upper basin characteristics on the North Fork are physiographically similar to those of the Upper Big Hole River above Wisdom, it would follow that flows at Wisdom should be about 45% of those at Mudd Creek. Nevertheless, on average, mean daily summer flows at Wisdom are significantly less than 45% of those at Mudd Creek. In 1999, mid-summer flows at Wisdom were commonly less than 20% of those at Mudd Creek (**Figure 2-5**). By fall, relative flow contributions from the mainstem of the Upper Big Hole increased to 40% of the total flow below Mudd Creek. The relatively low surface water yield from the Upper Big Hole sub-watershed above Wisdom during summer months indicates that dewatering is a more significant impact in the sub-watershed area above Wisdom than the North Fork Big Hole River sub-watershed.

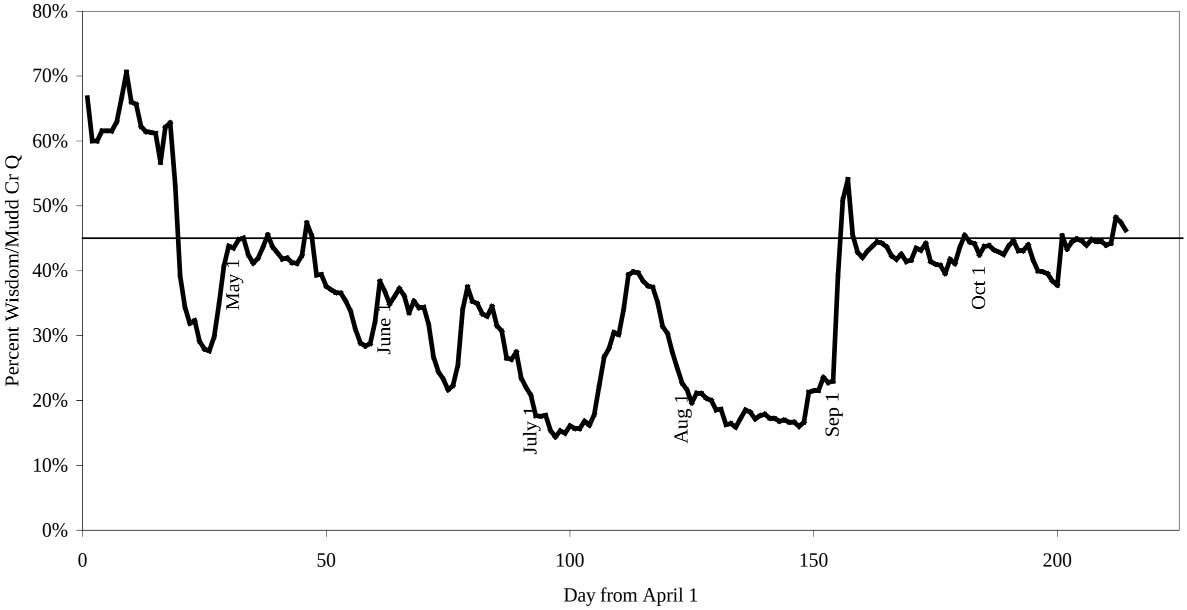

Figure 2-5: Ratio of mean daily flows on the Upper Big Hole River at Wisdom and near Mudd Creek.

The surface water hydrology of the Upper Big Hole River is typical of snowmelt driven watersheds. Peak discharges typically occur in the month of June, and the spring runoff event steeply recedes in July. The rate of flow recession following peak discharges tends to increase in the downstream direction from Jackson to below Mudd Creek. The flow duration and minimum flow assessments indicate that at the Wisdom gage instream flows were less than 20 cfs approximately 12% of the time. These minimum flows typically occurred during the months of June, July, August, and September. Analysis of relative contributions from sub-watersheds indicates the North Fork Big Hole River contributes more water relative to drainage size than the upper mainstem of the Big Hole River and its tributaries. This indicates that substantial dewatering occurs in the system upstream of Wisdom. As flood irrigation is widespread throughout the basin during late spring and summer, the reduction of instream flows during that period is systemic throughout the basin. However, the greatest relative impact of water use on the Big Hole River show surface flows evidently occur upstream of the North Fork confluence.

The Big Hole Drought Management Plan was adopted by the Big Hole Watershed Committee in partnership with Montana Department of Fish, Wildlife and Parks (FWP), Department of Natural Resources and Conservation (DNRC), and the U.S. Natural Resources Conservation Service (NRCS) in 1997. The plan has since been amended in 2000, 2002, 2004, 2005, and 2007. Its purpose is to mitigate the effects of low stream flows and lethal water temperatures for fisheries (particularly fluvial Arctic grayling) through a voluntary effort among agriculture, municipalities, business, conservation groups, anglers, and affected government agencies.

2.4.2 Ground Water/Surface Water Interactions

Interactions between ground water and surface water are an important component of the basin's hydrology. Connectivity between streams and the ground water table influences stream flow, especially at critical low flow periods. Understanding the dynamics between these waters is an essential element of water planning in the basin. This section describes the groundwater resource and its connectivity to surface waters.

Groundwater occurs in the permeable sands and gravels in the uppermost units within the Quaternary-age basin fill. Groundwater withdrawals in the basin are typically from this aquifer; the average well depth in the basin is 97 feet and average pumping level is 41 feet (DNRC 1995). Wells completed in the Tertiary and Quaternary sands and gravels typically produce about 5-20 gallons/minute (Marvin and Voeller 2000). Very shallow water table levels are common, especially during the maximum recharge period that extends from early spring to early summer.

Marvin and Voeller (2000) conducted a comprehensive investigation of ground water/surface water interactions in the Upper Big Hole River Basin during 1997 and 1998. These investigators integrated gaging station data, ground water elevations measured at 43 wells, climate data, and synoptic stream flow measurements from 20 tributaries. Using this data, the authors were able to assess several aspects of the groundwater resource and its influence on surface water. This includes seasonal and spatial patterns of groundwater storage, surface recharge dynamics, and losses to evapotranspiration.

Groundwater hydrographs for the basin depict a seasonal pattern influenced by snowmelt and irrigation practices (Marvin and Voeller 2000). Groundwater levels are lowest in winter and increase in March and April due to melting of the valley snowpack. Groundwater elevations continue to rise in May and June in response to contributions from the mountain snowpack and flood irrigation at lower elevations. Groundwater levels typically decline after mid-July following cessation of irrigation of hay meadows around July 4. Calculations based on average annual water changes suggest that groundwater storage in the basin is approximately 170,000 acre-feet

Groundwater hydrographs vary across the Upper Big Hole River Basin. The average annual water level change in the measured wells of the Upper Big Hole is about 5 ft. Still, marked variability occurs among wells. For example, in a well close to Governor Creek near Jackson, the 1996 peak water level occurred approximately one week after flood irrigation began in May, and, during those 6 days of irrigating, the water level rose 16.7 ft, or 2.8 ft/day. Active flood irrigation kept the water level relatively steady for the next 7 weeks. Irrigation ended on about July 9, 1996, and at that point the water levels dropped an average of 0.33 ft/day, until they stabilized in September at a level approximately 20 ft below the mid-summer peak.

Marvin and Voeller (2000) evaluated the extent of surface recharge from groundwater through several lines of evidence. First, a comparison of gaged total basin inflow to total outflow at the Mudd Creek gage indicated that during August 1998, inflows essentially balanced outflows (approximately 260 cfs). In September, however, outflows were approximately 32 cfs lower than inflows, indicating that groundwater contributions to surface flow failed to compensate fully for upstream surface-water losses related to evapotranspiration and seepage.

Next, the authors compared estimated basin water yield and measured surface water yield to draw inferences on the amount of water lost to evapotranspiration. With an average annual precipitation of 25.1 inches, the estimated total annual water yield delivered to the basin was 1.7 million acre-feet. Mean annual surface-water yield was approximately 456,000 acre-feet, which is approximately 27% of the total input. Mean annual evapotranspiration losses within the basin were therefore approximately 1.2 million acre-feet, or 18.3 inches (Marvin and Voeller 2000).

In addition to the general assessment of ground water/surface water interactions in the Upper Big Hole River Basin, Marvin and Voeller (2000) performed an intensive study within the Stanley, Sheep, and Francis Creek watersheds south of Wisdom (Francis Creek Unit). Data used in this evaluation included synoptic stream flow measurements on the streams and irrigation diversions and continuous flow measurements on the downstream end of Francis Creek, as well as on Huntley Ditch. These data were integrated with water levels measured in 23 wells within the unit.

Within the Francis Creek Unit, groundwater storage reductions in the fall and winter of 1997-1998 averaged 400 acre-feet/month. Between March and June 1998, total increase in storage was about 6,300 acre-feet. Natural melting of the valley snow pack contributed approximately 30% of this total, with the remainder (4200 acre-feet) attributable to recharge from irrigation in May and June. By September, storage dropped by approximately 4,500 acre-feet, of which an estimated 3,100 acre-feet was stored irrigation water. Marvin and Voeller attributed the reduction in water storage volume in July, August, and September to evapotranspiration processes, rather than surface or subsurface discharge.

Water balance results indicate that the 1998 evapotranspiration rates in the Francis Creek Unit were greatest during the month of July (4,800 acre-feet). For the entire 1998 growing season (May-September), evapotranspiration accounted for an estimated of 14,728 acre-feet of loss, which is approximately 57% of total input volume (Marvin and Voeller 2000). Assessment of irrigated acreage and associated evapotranspiration during the 1998 growing season corroborated these estimates. The evapotranspiration loss was 14,000 acre-feet, with grass hay consuming 64% of that value. Similarly, Levings (1986) estimated that approximately 73% of the total water delivered to the basin is lost to evapotranspiration.

In summary, the assessment of ground water storage trends, trends in surface water discharge, and evapotranspiration losses in the Francis Creek Unit indicate that although ground water storage increased by 4,200 acre-feet during the irrigation season (May and June), about that same amount was lost by subsequent evapotranspiration. This implies no correlation between the mid-to-late summer reduction in groundwater and surface water discharges. Thus, Marvin and Voeller (2000) concluded, “Irrigation returns appear to have a negligible effect on stream flow during the summer and early fall.” After the growing season, however, from October 1997 through February 1998, about 40% of the water released from groundwater storage was irrigation water. With relatively low evapotranspiration rates during that time of year, it is possible that irrigation water enhances surface water flows after the growing season ends.

2.5 Fluvial Geomorphology

Fluvial geomorphology refers to the study of the physical, morphological processes that operate within river systems and the landforms they create or have created. A number of factors influence fluvial geomorphology including basin geology, climate, vegetation, and hydrology. Because alterations in river geomorphology appear to be an issue with many 303(d) Listed streams in the Upper Big Hole River Basin, characterization of fluvial processes in the basin is an important component of watershed restoration planning. Integration of field observations, available documents, and interpretation of aerial photography provide the basis for the following geomorphic characterization of the Upper Big Hole Watershed.

2.5.1 General Setting

The Big Hole is the "highest and widest of the broad mountain valleys of western Montana" (Alt and Hyndman 1986). In the 1980s, wildcat oil well drilling revealed that the valley fill sediments are roughly 14,000 ft thick, which is far deeper than any other valley in the region. Erosion into this valley fill has resulted in the formation of terrace surfaces in the basin. The Tertiary-age Bozeman Formation underlies the highest surface. More recent alluvial deposits form additional terrace surfaces inset within the Bozeman Formation exposures. Glacial deposits, including outwash and moraines, are present on the basin margins.

2.5.2 Stream Morphology

As part of initial TMDL assessments, a basic Rosgen Level 1 stream classification of 303(d) Listed streams allowed segmentation of the channels into a series of reaches and broad categorization of the geomorphic character of each reach. This section provides a brief description of channel types identified in the classification effort (**Table 2-2**).

Observed channel types on the 303(d) Listed streams of the Upper Big Hole Basin range from steep, confined headwater channels to lower gradient channels in the valley bottoms. The geomorphic character of the individual stream segments is primarily a function of topography, geology, and land use. Proximal valley walls typically confine headwater channels, resulting in a lack of active floodplain area (A/B-type channels). In these areas, the valley walls are commonly steep timbered slopes with localized areas of timber harvest. The high elevation confined channels commonly transition into relatively broad glaciated valley bottoms that are relatively flat. Channels in these areas tend to be sinuous, stable stream segments that have willow dominated valley margins (E-type channels). As the streams enter the Upper Big Hole River Valley, the valley slope becomes more gradual. The streams in the basin tend to form sinuous threads that commonly occupy multiple active channels (DA-type channels). Commonly, reaches with multiple channel threads have a single, dominant C-type channel. In numerous areas, dense willows line the active channel margin, although the density of woody riparian vegetation is highly variable. Sediment storage in the form of bars is also variable; in most areas, little evidence of bar formation exists. In some reaches, however, such as those in which the channel abuts high terraces or where lateral migration rates are high, unvegetated point bars are common.

Table 2-2: Channel types (Rosgen 1996) identified on streams in the Upper Big Hole River Watershed in Level I classification activities.

Stream Type	Fundamental Characteristics
A	*A-Type Channels* are relatively steep channels that form in headwater areas as well as within bedrock canyons. These channels are entrenched and confined by steep valley margins such that little to no floodplain occurs on their border. As the boundaries of A-type channels are typically highly resistant to erosion, these stream types are generally quite resilient with respect to human impacts. The most common cause of geomorphic change within A-type channels is due to large scale sediment transport events, (landslides, debris flows, debris jam failure) that may result in blockage or deflection of channel flow.
B	*B-Type Channels* tend to form downstream of headwater channels, in areas of moderate slope where the watershed transitions from headwater environments to valley bottoms. Moderate slopes, moderate entrenchment, and stable channel boundaries characterize B-channels. Due to the relatively steep channel slopes and stable channel boundaries, B-channels are moderately resistant to human impacts, although, their reduced slopes relative to headwater areas can make them prone to sediment deposition and subsequent adjustment in the event of a large sediment transport event such as an upstream landslide, debris flow, or flood.
C	*C-Type Channels* are typically characterized by relatively low slopes, meandering plan forms, and pool/riffle sequences. The channels tend to occur in broad alluvial valleys, and they are typically associated with broad floodplain areas. C-channels tend to be relatively sinuous, as they follow a meandering course within a single channel thread. In stream systems in which the boundaries of C-type channels are composed of alluvial sediments, channels tend to dynamic in nature, and susceptible to rapid adjustment in response to disturbance.
D	*D-Type Channels* are braided channels that have open bar deposits between active channel threads. They tend to occur where sediment supply is abundant. They can commonly result from disturbances that increase sediment loads. D-channels are commonly aggradational, and are typically characterized by rapid rates of lateral adjustment.
DA	*DA-Type Channels* have multiple active channel threads that are relatively narrow and deep, separated by extensive, vegetated floodplains and wetlands. DA channels tend to form in areas of relatively low slope, with low bedload sediment volumes. Bank lines are typically very stable.
E	*E-Type Channels* are somewhat similar to C channels, as they form as single threads with defined, accessible floodplain areas. However, E channels are different in that they tend to have fine-grained channel margins, which provide cohesion and support dense bank line vegetation. The fine-grained, vegetation-reinforced bank lines allow for the development of steep banks, very sinuous plan forms, and relatively deep, U-shaped channel cross sections. E-type channels commonly form in low gradient areas with fine-grained source areas, mountain meadows, and in beaver-dominated environments. E-channels tend to have very stable plan forms, and efficient sediment transport capacities due to low width/depth ratios.

Table 2-2: Channel types (Rosgen 1996) identified on streams in the Upper Big Hole River Watershed in Level I classification activities.

Stream Type	Fundamental Characteristics
F	*F-Type Channels* typically have relatively low slopes (<2%), similar to C and E channel types. The primary difference between C/E channels and F channels is with respect to entrenchment. F channels are entrenched, which means that the floodplain is quite narrow relative to the channel width. The entrenchment of alluvial F-type channels typically is an indicator of an historic down cutting event. F-type channels may form in resistant boundary materials (e.g. U-shaped bedrock canyons), and relatively erodible alluvial materials (e.g. arroyos). When the boundary materials are erodible, the steep valley walls are prone to instability, and channel widening commonly occurs within the entrenched channel cross section.

Human influences on stream geomorphology are evident in the basin, especially along channels that occupy the valley bottoms. Numerous diversion structures are present along and within the channels, and the definition of the channels on aerial photographs is commonly reduced immediately downstream of major diversions. Riparian vegetation has been actively cleared from stream corridors, and locally stream segments have been straightened to accommodate infrastructure elements, such as highways and bridges.

2.5.3 Stream and Valley Geology Interaction

Reconnaissance-level field observations indicate that the primary types of sediment delivered to the river network include grus (granite-derived sand) and reworked alluvium consisting of gravels and coarse rounded cobbles/boulders. These particles tend to form an armor layer on the channel bed. The valley fill deposits exposed on terrace margins consist of relatively non-cohesive, poorly sorted, rounded alluvium. These deposits constitute a primary local sediment source for the Big Hole River and North Fork Big Hole River. As a result, the bed material is commonly bimodal, with a coarse, largely immobile lag substrate, and highly mobile sand. Gravel concentrations are higher where the channel directly accesses sediment from the terrace margins. Gravel concentrations appear to be relatively high in the Big Hole River upstream of Wisdom and on the North Fork Big Hole River.

2.5.4 Channel Evolution

A series of human activities over the last 200 years has affected the Upper Big Hole River system. In the 1800s, fur trappers described thousands of acres of riparian shrubs and beaver dams covering the valley. Beaver trapping in the intermountain west was dramatic, and the systemic reduction in beaver populations likely resulted in significant evolutionary changes in affected river channels. Some estimates suggest that 65 million beavers lived in North America 300 years ago (Wilkinson 2003). By the early 20th century, beaver populations had decreased to the point of being functionally extinct. The geomorphic implications of this extensive reduction in beaver populations are significant. Extensive beaver dams in river systems provide grade controls and result in the formation of complex channel networks with high water table levels that promote willow colonization. The consumption of willows by beavers promotes extensive suckering and active regeneration that increase bank stability. Beaver-dominated stream systems provide a complex in-channel habitat in the way of woody debris recruitment, pool formation, and trapping of fine sediment. Beaver dam-derived pools provide biological resilience to drought, and promote groundwater recharge (Wilkinson 2003). High flows result in periodic dam failure, which results in temporal shifts in primary channel dominance, sediment flushing, and habitat rejuvenation.

Documentation of the geomorphic effects of historic beaver removal in alluvial channels of the northern Rockies is limited; however, the topic is receiving increased attention due to ongoing watershed assessment efforts. In general, systems historically dominated by beavers show an evolution from marshy, wide, densely vegetated floodplain areas to less complex, entrenched channels and a narrower riparian corridor.

In the Upper Big Hole River Valley, descriptions of extensive beaver ponds, coupled with existing remnant stands of dense willows and associated multiple channel threads, suggest broad alluvial valley beaver ponding characterized the river system historically. The response to beaver removal was very likely simplification of the complex multi-channeled system. Entrenchment in the mainstem Big Hole River appears to have been limited due to the presence of very coarse substrate; however, this bed armoring resulted in localized channel widening as flow energy became concentrated in fewer active channels. Subsequent impacts of willow removal, intensive grazing, and flow diversions have further affected channel form and process. Results of the field reconnaissance and aerial assessment (Confluence et al. 2003) indicate that beaver removal, riparian corridor degradation, and instream flow diversion have resulted in reduced bank integrity, abandonment of side channels, reduced shading, and diminished small woody debris recruitment. The primary geomorphic response to these impacts have been increased flow conveyance within a primary channel thread, and increased width to depth ratio of the main channel and increased sheer stress on banks.

2.6 Vegetation

Plant community types within the Upper Big Hole River Watershed are typical of higher elevation areas of the Rocky Mountains ecoregion. The most detailed watershed wide assessment of vegetation types available for the Upper Big Hole Watershed is from the USGS GAP Analysis Program (GAP) vegetation project (Redmond et al. 1998). Vegetation types most abundant in the GAP analysis include lodgepole pine, mixed subalpine forest, and sagebrush (**Table 2-3**). Irrigated agricultural lands also comprise a significant portion of the watershed (9.3%). Coniferous forest dominates higher elevations; mid elevations have a combination of mixed forest, mesic shrubs, and sagebrush. Low elevation valleys typically possess a thin strip of riparian vegetation, the remaining area being almost entirely irrigated agricultural lands and low to moderate cover grasslands. Riparian vegetation comprises over 7% of the watershed, primarily in the form of shrub and understory riparian species. Overstory riparian vegetation is minimal unless conifers are present along streams in steeper gradient valleys in mountainous settings. Cottonwoods do not grow in this area because of natural limitations.

Table 2-3: Percent area of predominant vegetation types occurring in the Upper Big Hole Watershed TPA (Redmond et al. 1998).

Vegetation Cover Type	Percent Area
Lodgepole pine	21.7
Mixed subalpine forest	16.3
Sagebrush	13.9
Agricultural lands – irrigated	9.3
Low/moderate cover grasslands	8.5
Douglas fir	4.4
Mixed whitebark pine forest	3.8
Douglas fir/lodgepole pine	3.5
Montane parklands and subalpine meadows	3.5
Mixed mesic shrubs	2.5
Riparian shrubs	2.7
Rock	1.9
Riparian forbs and graminoids	1.8
Mixed riparian	1.1
Riparian conifer	1.0

2.7 Fisheries and Aquatic Life

The Upper Big Hole River Watershed supports prized fisheries in terms of both biodiversity and recreation. This includes a diverse mix of native and introduced species (**Table 2-4**). Species native to the drainage include fluvial Arctic grayling, westslope cutthroat trout, several species of sucker, burbot, mountain whitefish, and longnose dace. Recently, geneticists confirmed that a population of lake trout in Twin Lakes is an endemic population isolated from other lake trout populations by glaciers during the last ice age. Currently, this population is under review as a potential species of special concern due to its highly limited distribution, a condition that may increase its vulnerability to extinction (Montana Natural Heritage Program, personal communication). Introduced species include popular game species such as rainbow trout, brown trout, and brook trout. Common carp, a Eurasian species, is also present in the Upper Big Hole River.

Of particular interest is the fluvial Arctic grayling present in the mainstem of the Big Hole River and many of its major tributaries. This population is the last river dwelling population of Arctic grayling in the lower 48 states. Fluvial Arctic grayling were once widespread in the upper Missouri River drainage from its headwaters to Great Falls (Vincent 1962). Although lacustrine (lake dwelling) and adfluvial (migrating from lakes to streams) populations persist throughout this drainage, the fluvial form exists in only 4% of its historical range (Kaya 1992). Grayling are most abundant in the Big Hole River upstream of its confluence with the North Fork Big Hole River (Liknes and Gould 1987).

Grayling numbers in the Big Hole River Watershed have declined markedly from the early 1980s to the present causing considerable concern for the future of this population. Landowners, agencies, and conservation groups are actively pursuing solutions to reverse the decline and enhance recovery efforts for Arctic grayling. Reasons for the decline of fluvial Arctic grayling include habitat degradation, introduction of non-native salmonids, climatic change, and exploitation by anglers (Vincent 1962). Drought conditions during the late 1990s and early 2000s increased threats to the persistence of this population over the short term. Sampling efforts in 2002 found that catch-per-unit-efforts (CPUE) were the lowest since surveys began in 1978 (Magee and Lamothe 2003). Furthermore, biologists recently captured too few grayling to estimate population densities in key reaches of the Big Hole River (Magee and Lamothe 2003).

The westslope cutthroat trout is another species of special concern in the Upper Big Hole River Watershed. Westslope cutthroat trout have also experienced dramatic declines and are now present in 19-27% of their historic range in Montana (Van Eimeren 1996). In the Big Hole River Watershed, westslope cutthroat trout are presumably present in about 100 streams; however, they rate as abundant or common in only 26 of those streams (MFISH database, Natural Resources Information Service). Westslope cutthroat trout are present primarily in tributaries of the Big Hole River and are rarely present in the mainstem. Causes for the decline of westslope cutthroat trout include cumulative impacts of a number of factors. Similar to fluvial Arctic grayling, habitat degradation, introduced species, and dewatering have contributed to the decline of this species. In addition, hybridization with rainbow trout, and in some cases ,Yellowstone cutthroat trout, has greatly compromised the genetic integrity of westslope cutthroat trout throughout its range.

Table 2-4: Species of fish present in the Upper Big Hole River TMDL TPA and conservation status. Native species are presented in bold.

Family/species	**Scientific Name**	**Status***
Salmonidae		
Brook trout	*Salvelinus fontinalis*	
Westslope cutthroat trout	*Oncorhynchus clarki lewisii*	Species of special concern
Yellowstone cutthroat trout	*Oncorhynchus clarki bouvieri*	Species of special concern
Rainbow trout	*Oncorhynchus mykiss*	
Brown trout	*Salmo trutta*	
Mountain whitefish	*Prosopium williamsoni*	
Arctic grayling	*Thymallus arcticus*	Candidate for ESA
Westslope cutthroat trout × Yellowstone cutthroat trout	*O. clarki lewisii* × O. clarki bouvieri	
Rainbow trout × westslope cutthroat trout	*O. mykiss* × *O. clarki lewisii*	
Golden trout	*O. aguabonita*	
Lake trout	*Salvelinus namaycush*	Species under review
Cyprinidae		
Longnose dace	*Rhinichthys cataractae*	
Common carp	*Cyprinus carpio*	
Redside shiner	*Richardsonius balteatus*	
Catostomidae		
White sucker	*Catostomus commersoni*	
Longnose sucker	*Catostomus catostomus*	
Mountain sucker	*Catostomus platyrhynchus*	
Gadidae		
Burbot (ling)	*Lota lota*	
Cottidae		
Mottled sculpin	*Cottus bairdi*	

***Montana Natural Heritage Program and Montana Fish**

The Big Hole River Watershed also supports burbot (also known as ling) the only freshwater member of the cod family. Burbot occur in both the mainstem of the Big Hole River and in numerous tributaries, often at relatively high elevations. Although burbot are a native game species, little is known about their life history and status in Montana streams (personal communication, Dr. Christopher Guy, fisheries biologist, Montana State University). However, the presence of several age classes of burbot in Big Hole River Watershed streams suggests this population may be relatively secure. Fisheries researchers at Montana State University have recently begun a review of the status of this species, which may shed more light on the status of the Big Hole River Watershed population.

In addition to providing significant habitat for sensitive, native species, the Upper Big Hole River Watershed provides high quality fishing opportunities for non-native salmonids. Brook trout are the most abundant introduced species in the basin followed by brown trout. Rainbow trout are also present in many streams in the watershed, however, at relatively low numbers. These species draw anglers from throughout Montana and the US making the Upper Big Hole River one of the most popular streams in the state. In fact, the Upper Big Hole River frequently ranks within the top 20 streams in the state and the top 10 streams in the region based on angler pressure statistics (MFISH database). The popularity of this fishery contributes significantly to the local economy. In 1997, angling contributed over $8 million in revenue to the Big Hole River Watershed.

Amphibians are among the other taxa that rely on surface waters for at least part of their life cycles. According to Maxwell et al. (2003), the Upper Big Hole River Watershed supports several species of amphibian including the Rocky Mountain tailed frog (*Ascaphus montanus*), Columbia spotted frog (*Rana luteiventris*) and boreal toad (*Bufo boreas boreas*). Rocky Mountain tailed frogs occur primarily in forested, headwater reaches of streams in the watershed, although observers noted numerous specimens in McVey Creek at relatively low elevations during 2004 field investigations. The Columbia spotted frog is abundant throughout the valley portions of streams, a habitat where it is typically uncommon in Montana (Reichel and Flath 1995). Presumably, flood irrigation practices in the basin are favorable to this species by providing ample marshy areas lacking predators during their breeding season. The boreal toad is a subspecies of the western toad and is a species of special concern due to risks associated with very limited and potentially declining numbers, extent, and habitat making it vulnerable to global extinction or extirpation in the state (MNHP and MFWP 2002).

2.8 Land Use

Despite the challenging climate, the dominant land use in the Upper Big Hole River TPA is agriculture. Ranchers pasture their livestock on National Forest ranges in the summer and grow irrigated hay for winter feed in the valley bottom, or they summer pasture in the valley bottom and move their livestock out of the basin in the winter. Flood irrigation is used to grow hay throughout the valley bottom with the irrigation season being from early May through mid-July (USFS unpublished data).

Hay production has long been a hallmark of the Big Hole River Valley. The combined practices of hay production and winter-feeding allowed ranchers in the Big Hole River Valley to weather the especially harsh winter of 1886-1887 when ranchers in other parts of the state lost an average of 55% of their herds (Munday 2001). The Big Hole River Valley became renowned as the “land of 10,000 haystacks,” a reputation facilitated by the local invention of the beaver slide hay-stacker (Munday 2001).

While hay production is still a principal land use in the Upper Big Hole River, there has been a declining trend over the past 20 years. Hay meadows have been converted to irrigated pastures, and cows and calves are often transported to lower elevations to overwinter. This change in land use has resulted in changes in water use in the basin. While irrigation of hay meadows typically ceased after the first cutting sometime in the early summer, irrigation of pastures for forage production occurs throughout the entire summer. Removal of water from the Big Hole River during the hottest part of the summer has implications for stream temperatures and Arctic grayling. Moreover, these practices have implications for forage production, favoring less nutritious sedges and other wetland species in uplands.

Logging and associated activities such as road construction occur in forested portions of the watershed. Spatial data describing extent and timing of timber harvest activities were unavailable for this phase of TMDL development. Still, restoration priority information provided by the US Forest Service (USFS) indicates that several tributaries receive increased sediment loads from roads. Based on information provided by the USFS, it appears that silvicultural practices in the Upper Big Hole River TPA have improved since the mid-1980s.

Relatively little historic mining and prospecting activity has occurred in the planning area. The Montana Bureau of Mines and Geology abandoned mines database lists 59 mines and prospects in this area. Of these, seven are located in the Steel Creek Watershed, which is listed as impaired for metals. Of these seven, one is under consideration for remediation.

Urban or residential development comprises very little of the Upper Big Hole River TPA. Jackson and Wisdom are the only towns and each has populations of about 100 people (2000 census data). Otherwise, residents of the Upper Big Hole River Valley live on widely spaced ranches. Overall, the Upper Big Hole River Watershed has escaped much of the development pressures facing other small, Montana communities. Harsh, long winters and hoards of mosquitoes in the summer are commonly identified constraints to subdivisions and recreational property development.

SECTION 3.0
TMDL REGULATORY FRAMEWORK

3.1 TMDL Development Requirements

Section 303(d) of the Federal Clean Water Act (CWA) requires states to identify water bodies within its boundaries that do not meet water quality standards. States track these impaired or threatened water bodies with a 303(d) List. Recently the name for the 303(d) List has changed to Montana's Water Quality Integrated Report. State law identifies that a methodology for determining the impairment status of each water body is used for consistency and the actual methodology is identified in **Appendix A** of Montana's Water Quality Integrated Report.

Under Montana State Law, an "impaired water body" is defined as a water body or stream segment for which Sufficient Credible Data (SCD) show that the water body or stream segment is failing to achieve compliance with applicable water quality standards (Montana Water Quality Act; Section 75-5-103(11)). A "threatened water body" is defined as a water body or stream segment for which SCD and calculated increases in loads show that the water body or stream segment is fully supporting its designated uses, but threatened for a particular designated use because of (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 (Montana Water Quality Act; Section 75-5-103(31)). State Law and Section 303 of the CWA require states to develop TMDLs for impaired or threatened water bodies.

A TMDL is a pollutant budget for a water body identifying the maximum amount of the pollutant that a water body can assimilate without causing applicable water quality standards to be exceeded. 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 need to incorporate a margin of safety and consider seasonality. In Montana, TMDL development is often accomplished in the context of an overall water quality plan. The water quality plan includes not only the actual TMDL, but also includes information that can be used to effectively restore beneficial water uses that have only been affected by pollution, such as habitat degradation or flow modification, that are not covered by the TMDL program.

To satisfy the Federal Clean Water Act and Montana State Law, TMDLs are developed for each water body-pollutant combination identified on the state's list of impaired or threatened waters and are often presented within the context of a water quality restoration or protection plan. State Law (Administrative Rules of Montana 75-5-703(8)) also directs 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 water bodies 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. Montana TMDL laws provide a 5-year review process to allow for an adaptive management approach to update the TMDL and Water Quality Restoration Plan (WQRP).

3.2 Water Bodies and Pollutants of Concern

Category five of the Montana's Integrated Water Quality Report drives the scope of each TMDL project. Some streams within this TMDL planning area do not have sufficient information for 303d assessment or have been deemed as fully supporting all uses and meeting water quality standards and therefore may not be mentioned in this report. See Montana's Integrated Water Quality Report to determine the status of 303d assessment for streams not addressed within this document (http://www.deq.state.mt.us/wqinfo/303_d/what_is_303d.asp and http://cwaic.mt.gov/).

Most pollutant/stream combinations identified on the 2006 list are addressed; however, a few are not addressed at this time due to project and time constraints. These listings will be identified in a follow up monitoring strategy and addressed within a timeframe identified in Montana's law (*Montana Code Annotated 75-5-703*). However, TMDLs were not prepared for impairments where additional information suggests that the initial listings were inaccurate or where conditions had improved sufficiently since the listing to an extent that the pollutant no longer impairs a beneficial use. Where a pollutant is recommended for removal from the list, good cause justification is provided in the sections that follow. **Tables 3-1 and 3-2** provide a summary of water body information for the 2006 303(d) List for the Upper and North Fork Big Hole River TPAs. The integrated report identifies impaired waters by a Montana water body segment ID, which is indexed to the National Hydrography Dataset.

Table 3-1: Water Bodies on Montana's 303(d) List of Impaired Waters and Their Associated Level of Beneficial Use Support.

Water Body & Stream Description	Water Body #	Use Class	Aquatic Life	Fisheries - Cold	Drinking Water	Swimmable (Recreation)	Agriculture	Industry
Big Hole River, above Pintlar Creek	MT41D001-030	A-1	P	P	F	P	F	F
North Fork Big Hole River, headwaters to mouth (Big Hole River)	MT41D004-010	A-1	P	P	X	P	X	X
Mussigbrod Creek, headwaters to mouth (North Fork Big Hole River)	MT41D004-020	A-1	N	N	N	P	F	F
Johnson Creek, headwaters to mouth (North Fork Big Hole River)	MT41D004-030	A-1	P	P	F	P	F	F
Schultz Creek, headwaters to mouth (Johnson Creek)	MT41D004-040	A-1	P	P	F	F	F	F

Table 3-1: Water Bodies on Montana's 303(d) List of Impaired Waters and Their Associated Level of Beneficial Use Support.

Water Body & Stream Description	Water Body #	Use Class	Aquatic Life	Fisheries - Cold	Drinking Water	Swimmable (Recreation)	Agriculture	Industry
Tie Creek, headwaters to mouth (North Fork Big Hole River)	MT41D004-060	A-1	P	P	F	F	F	F
Trail Creek, Headwaters to Joseph Creek	MT41D004-070	A-1	P	P	F	F	F	F
Trail Creek, Joseph Creek to mouth (North Fork Big Hole River)	MT41D004-080	A-1	P	P	F	F	F	F
Joseph Creek, headwaters to mouth (Trail Creek-North Fork Big Hole River)	MT41D004-090	A-1	P	P	N	F	F	F
Ruby Creek, headwaters to mouth (North Fork Big Hole River)	MT41D004-100	A-1	P	P	F	P	F	F
Swamp Creek, headwaters to mouth (Big Hole River)	MT41D004-110	A-1	P	P	F	N	F	P
Rock Creek, headwaters to mouth (Big Hole River)	MT41D004-120	A-1	P	P	F	F	F	F
Miner Creek, headwaters to mouth (Big Hole River)	MT41D004-140	A-1	P	P	X	F	X	F
Governor Creek, headwaters to mouth (Big Hole River-South of Jackson)	MT41D004-150	A-1	N	N	F	P	F	F
Pine Creek, headwaters to mouth (Andrus Creek-Governor Creek)	MT41D004-160	A-1	P	P	F	P	F	F
Fox Creek, headwaters to mouth (Governor Creek)	MT41D004-170	A-1	P	P	F	F	F	F
Warm Springs Creek, headwaters to mouth (Big Hole River-Near Jackson)	MT41D004-180	A-1	P	P	F	P	F	P
Steel Creek, headwaters to mouth (Big Hole River)	MT41D004-190	A-1	N	N	N	P	F	F
Francis Creek, headwaters to mouth (Steel Creek) T3S R15W	MT41D004-200	A-1	P	P	F	F	F	F
McVey Creek, headwaters to mouth (Big Hole River) T1S R15W	MT41D004-210	A-1	P	P	F	F	F	F
Doolittle Creek, tributary to the Big Hole River T1S, R14W	MT41D004-220	A-1	P	P	F	P	F	P

Table 3-1: Water Bodies on Montana's 303(d) List of Impaired Waters and Their Associated Level of Beneficial Use Support.

Water Body & Stream Description	Water Body #	Use Class	Aquatic Life	Fisheries - Cold	Drinking Water	Swimmable (Recreation)	Agriculture	Industry
Pintlar Creek, headwaters to mouth (Big Hole River)	MT41D003-170	A-1	P	P	F	P	F	F
Little Lake Creek, headwaters to mouth (Big Hole River)	MT41D004-130	A-1	F	F	F	F	F	F

Legend - **F**= Full Support; **P**= Partial Support; **N**= Not Supported; **T**= Threatened; **X**= Not Assessed (Insufficient Credible Data)

Table 3-2 lists the water bodies on the 2006 303(d) List of impaired waters. Probable causes of impairment, as identified on the 2006 list, includes sediment-related listings (siltation, suspended solids, turbidity, bank erosion), metals (cadmium, copper, lead, mercury, and zinc), thermal modification, nutrients, riparian and fish habitat degradation, habitat alteration, habitat modification, channel incisement, and flow alteration (dewatering). Metals, temperature, nutrients, and sediment TMDLs are needed for specific water bodies in this TPA. Habitat and flow related listings are pollution related and will likely be addressed as sources of pollutants in this document.

Table 3-2: Probable Cause(s) and Source(s) for Impaired Waters.

Water Body	2006 Causes	2006 Sources
Big Hole River, above Pintlar Creek	Alteration in stream-side or littoral vegetative covers Low flow alterations Temperature	Highways, roads, bridges, infrastructure (New Construction) Loss of riparian habitat Rangeland grazing Agriculture Irrigated crop production
North Fork Big Hole River, headwaters to mouth (Big Hole River)	Alteration in stream-side or littoral vegetative covers Low flow alterations Sedimentation/Siltation	Grazing in Riparian or Shoreline Zones Loss of Riparian Habitat Silviculture Activities Irrigated Crop Production Highway/Road/Bridge Runoff (Non-construction Related)

Table 3-2: Probable Cause(s) and Source(s) for Impaired Waters.

Water Body	2006 Causes	2006 Sources
Mussigbrod Creek, headwaters to mouth (North Fork Big Hole River)	Lead Alteration in stream-side or littoral vegetative covers Low flow alterations Other anthropogenic substrate alterations Physical substrate habitat alterations	Acid Mine Drainage Impacts from Abandoned Mine Lands (Inactive) Grazing in Riparian or Shoreline Zones Loss of Riparian Habitat Rangeland Grazing Agriculture Impacts from Hydrostructure Flow Regulation/modification Irrigated Crop Production Natural Sources
Johnson Creek, headwaters to mouth (North Fork Big Hole River)	Alteration in stream-side or littoral vegetative covers Low flow alterations Sedimentation/Siltation Total Kjehldahl Nitrogen (TKN)	Grazing in Riparian or Shoreline Zones Irrigated Crop Production Silviculture Harvesting
Schultz Creek, headwaters to mouth (North Fork Big Hole River)	Sedimentation/Siltation	Forest Roads (Road Construction and Use) Grazing in Riparian or Shoreline Zones Silviculture Harvesting
Tie Creek, headwaters to mouth (North Fork Big Hole River)	Physical substrate habitat alterations Sedimentation/Siltation Nitrogen (Total)	Rangeland Grazing Silviculture Activities Unspecified Unpaved Road or Trail
Trail Creek, Joseph Creek to mouth (North Fork Big Hole River)	Physical substrate habitat alterations Sedimentation/Siltation	Grazing in Riparian or Shoreline Zones Impacts from Abandoned Mine Lands (Inactive) Streambank Modifications/Destabilization Silviculture Activities Unspecified Unpaved Road or Trail
Trail Creek, headwaters to confluence with Joseph Creek	Physical substrate habitat alterations* Sedimentation/Siltation*	Grazing in Riparian or Shoreline Zones Impacts from Abandoned Mine Lands (Inactive) Streambank Modifications/Destabilization Silviculture Activities Unspecified Unpaved Road or Trail
Joseph Creek, headwaters to mouth (Trail Creek-North Fork Big Hole River)	Lead Copper Physical Substrate habitat alterations Sedimentation/Siltation	Impacts from Abandoned Mine Lands (Inactive) Channelization Highways, Roads, Bridges, Infrastructure (New Construction) Silviculture Harvesting

Table 3-2: Probable Cause(s) and Source(s) for Impaired Waters.

Water Body	**2006 Causes**	**2006 Sources**
Ruby Creek, headwaters to mouth (North Fork Big Hole River)	Alteration in stream-side or littoral vegetative covers Low flow alterations Physical substrate habitat alterations Sedimentation/Siltation	Grazing in Riparian or Shoreline Zones Loss of Riparian Habitat Rangeland Grazing Silviculture Activities Impacts from Hydrostructure Flow Regulation/Modification Irrigated Crop Production Dredge Mining Forest Roads (Road Construction and Use) Unspecified Unpaved Road or Trail
Swamp Creek, headwaters to mouth (Big Hole River)	Alteration in stream-side or littoral vegetative covers Low flow alterations Sedimentation/Siltation Nitrogen (Total) Phosphorus (Total)	Grazing in Riparian or Shoreline Zones Loss of Riparian Habitat Irrigated Crop Production
Rock Creek, headwaters to mouth (Big Hole River)	Alteration in stream-side or littoral vegetative covers Low flow alterations Physical substrate habitat alterations Sedimentation/Siltation Nitrogen (Total) Phosphorus (Total)	Grazing in Riparian or Shoreline Zones Loss of Riparian Habitat Agriculture Impacts from Hydrostructure Flow Regulation/modification Irrigated Crop Production
Miner Creek, headwaters to mouth (Big Hole River)	Sedimentation/Siltation	Forest Roads (Road Construction and Use) Grazing in Riparian or Shoreline Zones
Governor Creek, headwaters to mouth (Big Hole River-South of Jackson)	Alteration in stream-side or littoral vegetative covers Copper Low flow alterations Other anthropogenic substrate alterations Physical substrate habitat alterations	Grazing in Riparian or Shoreline Zones Loss of Riparian Habitat Agriculture Impacts fro Hydrostructure Flow Regulation/modification Irrigated Crop Production Habitat Modification-other than Hydromodification
Pine Creek, headwaters to mouth (Andrus Creek-Governor Creek)	Alteration in stream-side or littoral vegetative covers Phosphorus (Total)	Rangeland Grazing

Table 3-2: Probable Cause(s) and Source(s) for Impaired Waters.

Water Body	**2006 Causes**	**2006 Sources**
Fox Creek, headwaters to mouth (Governor Creek)	Phosphorus (Total)	Grazing in Riparian or Shoreline Zones
Warm Springs Creek, headwaters to mouth (Big Hole River-Near Jackson)	Alteration in stream-side or littoral vegetative covers Low flow alterations Sedimentation/Siltation Total Kjehldahl Nitrogen (TKN) Phosphorus (Total)	Grazing in Riparian or Shoreline Zones Loss of Riparian Irrigated Crop Production
Steel Creek, headwaters to mouth (Big Hole River)	Cadmium Alteration in stream-side or littoral vegetative covers Copper Low flow alterations Other anthropogenic substrate alterations Physical substrate habitat alterations Phosphorus (Total)	Acid Mine Drainage Impacts from Abandoned Mine Lands (Inactive) Grazing in Riparian or Shoreline Zones Loss of Riparian Habitat Rangeland Grazing Agriculture Impacts from Hydrostructure Flow Regulation/modification Irrigated Crop Production Habitat Modification-other than Hydromodification
Francis Creek, headwaters to mouth (Steel Creek) T3S R15W	Alteration in stream-side or littoral vegetative covers Sedimentation/siltation Nitrogen (Total) Phosphorus(Total)	Grazing in Riparian or Shoreline Zones
McVey Creek, headwaters to mouth (Big Hole River) T1S R15W	Alteration in stream-side or littoral vegetative covers Sedimentation/siltation Nitrogen (Total) Phosphorus (Total)	Grazing in riparian or shoreline zones
Doolittle Creek, tributary to the Big Hole River T1s R14W	Alteration in stream-side or littoral vegetative covers Low flow alterations Sedimentation/siltation	Highways, Roads, Bridges, Infrastructure (New Construction) Agriculture Irrigated crop production

Table 3-2: Probable Cause(s) and Source(s) for Impaired Waters.

Water Body	2006 Causes	2006 Sources
Pintlar Creek	Other flow regime alterations Low flow alterations Physical substrate habitat alterations Temperature	Impacts from hydrostructure Flow regulation/modification Irrigated crop production Impacts from abandoned mine lands (Inactive) Grazing in riparian or Shoreline zones

* Impairment causes will be identified in the 2008 impaired waters list.

Impairment status and impairment list reviews will also be provided for each water body in **Section 5.0** of this document in text form.

3.3 Applicable Water Quality Standards

Water quality standards include the uses designated for a water body, the legally enforceable standards that ensure that the uses are supported, and a non-degradation policy that protects the high quality of a water body. The ultimate goal of these TMDLs and framework Water Quality Restoration Plan, once implemented, is to ensure that all designated beneficial uses are fully supported and all standards are met. Water quality standards form the basis for the targets described in **Section 3.3**. Pollutants addressed in this plan include nutrients, sediment, metals, and thermal modification. This section provides a summary of the applicable water quality standards for each of these pollutants.

3.3.1 Classification and Beneficial Uses

Classification is the assignment (designation) of a single or group of uses to a water body based on the potential of the water body 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 Water Quality Act (WQA) directs the Board of Environmental Review (BER, i.e., the state) to establish a classification system for all waters of the state that include 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 include 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 water body must be maintained suitable for that designated use. When natural conditions limit or preclude a designated use, permitted point source discharges or nonpoint source discharges may not make the natural conditions worse.

Modification of classifications or standards that would lower a water's classification or standard (i.e., 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 U.S. 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 3-3**. All water bodies within the Upper Big Hole TPA are classified as A-1.

Table 3-3: Montana Surface Water Classifications and Designated Beneficial Uses Applicable to the Upper Big Hole Watershed.

Classification	Designated Uses
A-1 CLASSIFICATION:	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. Water quality must 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.

3.3.2 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 surface water quality standards have been developed for many parameters to protect human health and aquatic life. These standards are in the Department Circular WQB-7 (DEQ, January 2004). 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., life long) exposure by water consumption, as well as through direct contact, such as swimming.

The numeric aquatic life standards 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 either be "non-significant" or an authorization to degrade must be granted by the Department. 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 water body.

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 water body. 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 standards applicable to the list of pollutants addressed in the Upper Big Hole TPA are summarized one-by-one below.

Sediment

Sediment (i.e., coarse and fine bed sediment) and suspended sediment are addressed via the narrative criteria identified in **Table 3-4**. 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 reference condition that reflects a water body's greatest potential for water quality given current and historic land use activities where all reasonable land, soil, and water conservation practices have been applied and resulting conditions are not harmful, detrimental, or injurious to beneficial uses (see definitions in **Table 3-4**).

Table 3-4: Applicable Rules for Sediment Related Pollutants.

Rule(s)	Standard
17.30.623(2)	No person may violate the following specific water quality standards for waters classified A-1.
17.30.623(2)(f)	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.
17.30.637(1)	State surface waters must be free from substances attributable to municipal, industrial, agricultural practices, or other discharges that will.
17.30.637(1)(a)	Settle to form objectionable sludge deposits or emulsions beneath the surface of the water or upon adjoining shorelines.
17.30.637(1)(d)	Create concentrations or combinations of materials that are toxic or harmful to human, animal, plant, or aquatic life.
	The maximum allowable increase above naturally occurring turbidity is 0 NTU for A-closed; 5 NTU for A-1, B-1, and C-1; 10 NTU for B-2, C-2, and C-3.

Table 3-4: Applicable Rules for Sediment Related Pollutants.

Rule(s)	Standard
17.30.602(17)	"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.
17.30.602(21)	"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.

Metals

Numeric standards for water column metals in Montana include specific standards for the protection of both aquatic life and human health. Acute and chronic criteria have been established for the protection of aquatic life. The criteria for some metals vary according to the hardness of the water. The applicable numeric metals standards (guidelines for aquatic life), for the specific metals of concern in the Upper Big Hole TPA, are presented in **Table 3-5**. Actual standards for aquatic life at any given hardness are calculated using **Equation 3-1** and **Table 3-6**. The actual standards are used to determine standards exceedences in this document, not the guidance from **Table 3-5**. Existing data indicates that other metals are below water quality standards.

It should be noted that recent studies have indicated in some streams metals concentrations may vary through out the day because of diel pH and alkalinity changes. In some cases the variation can cross the standard threshold (both ways) for a metal. Montana water quality standards are not time of day dependent.

Table 3-5: Montana Numeric Surface Water Quality Standards Guide for Metals.

Parameter	Aquatic Life (acute) (µL)[a]	Aquatic Life (chronic) (µL)[b]	Human Health (µL)[a]
Cadmium	0.52 @ 25 mg/L hardness	0.97 @ 25 mg/L hardness	5
Copper	3.79 @ 25mg/L hardness	8.25 @ 25 mg/L hardness	1,300
Lead	13.98 @ 25 mg/L hardness	0.545 @ 25 mg/L hardness	15
Mercury (TR)	1.7	0.91	0.05
Zinc (TR)	37 @ 25 mg/L hardness[c]	37 @ 25 mg/L hardness[c]	2,000

[a]Maximum allowable concentration.
[b]No 4-day (96-hour) or longer period average concentration may exceed these values.
[c]Standard is dependent on the hardness of the water, measured as the concentration of $CaCO_3$ (mg/L) (see **Table 3-6** for the coefficients to calculate the standard).
Note: TR – total recoverable.

Hardness-based standards for aquatic criteria are calculated using the following equation and are used for determining impairment:

Equation 3-1:

Chronic = exp.{mc[ln(hardness)]+bc} where mc and bc are values from **Table 3-6**

Table 3-6: Coefficients for Calculating Metals Freshwater Aquatic Life Standards (DEQ 2002).

Parameter	ba (acute)	bc (chronic)
Cadmium	-3.924	-4.719
Copper	-1.700	-1.702
Lead	-1.46	-4.705
Zinc	0.884	0.884

Note: If hardness is <25 mg/L as CaCO3, the number 25 must be used in the calculation. If hardness is equal or greater than 400 mg/L as CaCO3, 400 mg/L must be used for the hardness value in the calculation.

Montana also has a narrative standard that pertains to metals in sediment. No increases are allowed above naturally occurring concentrations of sediment or suspended sediment (except as 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 (ARM 17.30.623(2)(f)). This narrative standard includes metals-laden sediment.

Temperature

Montana's 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 rate at which temperature changes (i.e., above or below naturally occurring) can occur to avoid fish and aquatic life temperature shock.

For waters classified as A-1 or B-1, the maximum allowable increase over naturally occurring temperature (if the naturally occurring temperature is less than 67ºF) is 1°F and the rate of change cannot exceed 2°F per hour. If the natural occurring temperature is greater than 67ºF, the maximum allowable increase is 0.5ºF (ARM 17.30.622(e), ARM 17.30.623(e)).

Nutrients

There are no statewide numeric Aquatic Life standards for nutrients. Numeric human health standards exist for nitrates. Human health standards for nitrogen are listed in **Table 3-7**.

Table 3-7: Human Health Standards for Nitrogen for the State of Montana.

Parameter	Human Health Standard (µL)*
Nitrate as Nitrogen (NO_3-N)	10,000
Nitrite as Nitrogen (NO_2-N)	1,000
Nitrate plus Nitrite as N	10,000

*Maximum Allowable Concentration

Waters of Montana are protected from excessive nutrient concentrations by narrative standards. The exception is the Clark Fork River above the confluence with the Flathead River where numeric water quality standards for total nitrogen (300 µg/L) and total phosphorus (20 µg/L upstream of the confluence with the Blackfoot River and 39 µg/L downstream of the confluence), as well as algal biomass measured as chlorophyll-*a* (summer mean and maximum of 100 and 150 mg/m^2, respectively), have been established.

The narrative standards applicable to nutrients that protect all uses elsewhere in Montana are contained in the General Prohibitions of the surface water quality standards (ARM 17.30.637 et. Seq.). The prohibition against the creation of "*conditions which produce undesirable aquatic life*" is generally the most relevant to nutrients.

3.3.3 Reference Approach for Narrative Standards

When possible, a reference site approach is used to determine the difference between an impacted area and a "natural" or least impacted water body. The reference site approach is the preferred method to determine naturally occurring conditions; but, when appropriate reference sites are not easily found, modeling, or regional reference literature values are used.

SECTION 4.0
WATER QUALITY TARGETS

The water quality targets presented in this section are based on the best available science and information available at the time this document was written. TMDL targets are not stagnant components of this plan. Targets will be assessed during future TMDL reviews for their validity when new information may be available.

Targets help identify conditions that protect beneficial uses. Targets also help evaluate compliance with standards and serve as goals by which to measure the progress of future restoration efforts. For pollutants with numeric standards, compliance with that standard is, by default, a numeric target. Nevertheless, most of the pollutants in the Upper and North Fork Big Hole TPAs have some type of associated narrative standards (**Section 3.0**). Because of the ambiguity associated with narrative standards and variability in field conditions that may affect application of narrative standards, DEQ will use multiple lines of evidence for metal, nutrient, thermal conditions, and sediment target setting within the Upper and North Fork Big Hole TPAs. Supplemental indicator levels are sometimes presented for measures that provide strong supporting evidence for determining if a TMDL will be pursued. Also, other supporting information may be provided for clarifying if a TMDL will be pursued.

A number of the targets and indicators presented in this document are based on internal reference conditions. The targets and indicators which contain a rationale using an internal reference condition for threshold settings are related to site condition in this case, and not watershed condition. These types of parameters include riparian vegetation condition and bank erosion. The term "reference" is used for reaches of stream that are considered to have current and historic reasonable land use conservation practices in place for the applicable land use at the site. In this document, the term "reference" does not imply a reference watershed where upstream land or water use practices are in a "reference" condition. The reference sites are not to be considered reference watersheds and do not relate well to all targets presented in this document, notably those that are more dependant upon watershed scale sources such as fine sediment, water chemistry, or stream flow measures. Other targets are based on regional or historical reference data, but when appropriate reference data are sparse or non-existent, secondary reference approaches can be applied. These secondary approaches include modeling, literature reviews, and professional judgment. In many situations, a combination of reference site and secondary reference approaches are used to establish reference conditions.

4.1 Thermal Targets

Thermal targets are provided for the Big Hole River and Pintlar Creek. Targets incorporate the use of Montana's water quality temperature standard and the factors that influence water temperatures. Temperature modeling was used as a tool to determine if Montana's water quality temperature standards are likely being met or exceeded in the Big Hole River above the North Fork Confluence. Targets also incorporate the relationship between channel geometry, riparian shading, and flow volumes in maintaining cool temperatures. The linkage between temperature conditions and fishery impacts is also investigated. Because any one approach to setting temperature targets has uncertainty, a number of targets will be used.

4.1.1 Temperature

4.1.1.1 Montana's Temperature Standard

Interpretation of Montana's narrative temperature standards can be difficult. The standards designate that only a specific derivation from the natural occurring temperature condition is tolerable (**Section 3.0**). Thermal modeling was used as a tool to indicate that Montana's water quality standards are likely exceeded in the Upper Big Hole River. The TMDL assessment used monitoring data from reference and non-reference reaches to model temperature conditions with varying stream flows and reference physical conditions on two short reaches of the Big Hole River (**Appendix B**). Although a high level of modeling certainty was desired, thermal modeling for the whole Upper Big Hole River was not feasible because of the complex nature of the natural stream channels and the irrigation network in this TPA. Continuous temperature monitoring, riparian shade, stream flow, and channel dimensions were monitored on the upper and lower section on two reaches of the Upper Big Hole River. This information was used to model temperature conditions with varying influencing factors to simulate the difference between existing conditions and reasonable land, soil, and water conservation practices. The difference in temperatures is used to indicate if Montana's water quality temperature standard is likely being met or exceeded.

Also, the targets will incorporate an "or" statement where Montana's temperature standards should be met or all the reference physical condition targets should be met in combination. In this approach, if all reasonable land, soil, and water conservation practices are installed, state standards are met. Yet, if the temperature standards are met, the use is supported, and not all areas need to have full installation of restoration practices to meet the standards.

4.1.1.2 Width-to-Depth Ratios

A numeric target for temperature is width-to-depth ratio, calculated by dividing the bankfull width by the average bankfull depth. Average bankfull depths were calculated by dividing the bankfull width by cross section area. Impacted reaches of the Big Hole River had substantially greater width-to-depth ratios than reference reaches. This relates to thermal loading because the high-surface-area-to-volume ratio in over widened reaches decreases thermal inertia allowing water to heat more readily. Also, a narrower channel receives increased shade from a constant sized riparian canopy when compared to a wider channel.

The target for width-to-depth ratios for the Big Hole River mainstem calls for the 75^{th} percentile of any assessed reach's width-to-depth to approximate or be less than 43, which is the 75^{th} percentile for the reference reaches (**Table 4-1**). Minor exceedences of the target value, or exceedences that are within statistical expectations, will result in little, if any, weighing toward determining if a TMDL is needed. The 75^{th} percentile of the reference population is used as a comparative statistic because lower width-to-depth ratios are desirable for reducing water temperature. Comparing median reference and non-reference statistics may also indicate if there is a shift toward widened streams from reference conditions where reasonable land practices are occurring and may be considered. Applying this target to assessed reaches of the Big Hole River indicates all the reference reaches met these criteria; however, most impacted reaches exceeded the target substantially. For Pintlar Creek, width-to-depth ratios measured on valley reference tributaries provided the basis for targets (**Table 4-1**). Consequently, Pintlar Creek's target for width-to-depth ratio is for the 75th percentile to be less than or approximately 19.5, following the same rationale as the targets presented for the mainstem of the Big Hole River. Median statistics may also be used for assessing if width-to-depth ratios are over wide.

The width-to-depth ratios reported for the Upper Big Hole TMDL project are collected at set intervals along a reach of stream and may fall at any type of stream channel area. These width-to-depth ratios are representative of cumulative widths measures, but not comparable to with-to-depth ratios collected only at riffle cross sections.

Table 4-1: Select descriptive statistics for width-to-depth ratios measured on reference and impacted reaches of the Big Hole River and Pintlar Creek.

Reach Type/Name	N	Minimum	Maximum	25th percentile	Median	75th Percentile
Big Hole River						
Reference	15	8	43	21	22	26
Impacted	30	4	82	34	45	58
Pintlar Creek						
Pintlar Creek	9	4	15	11	11	14
Valley reference tributaries	39	4	30	10	14	20

4.1.1.3 Canopy Density

Measurement of riparian canopy density over the stream using a handheld spherical densitometer (Lemmon 1956) is used as a target. On the Big Hole River, canopy density on reference reaches was significantly greater than on impacted reaches. The target for canopy density at streambanks is that the 25th percentile canopy density must approximate or be more than 31.5 percent, which is the 25th percentile of reference reaches (**Table 4-2**). Minor exceedences of the target value, or exceedences that are within statistical expectations, will result in little, if any, weighing toward determining if a TMDL is necessary while those with greater exceedence will be weighed more heavily. Selection of the lower quartile relates to this measure usually showing a non-normal distribution, making the upper quartiles more variable. Comparing median reference and non-reference statistics may also indicate if there is a shift toward less riparian shading from reference conditions where reasonable land practices are occurring and may also be used to determine if a TMDL is needed. Comparisons of shading on assessed reaches indicated that most impacted reaches failed to meet the target. The canopy density target for Pintlar Creek is provided by applying the same rationale for the Big Hole mainstem target setting strategy to valley tributary reference sites (**Table 4-2**). This temperature target only applies to sites where shrubs are the predominant riparian growth potential. Riparian tree harvest was not found during aerial photo reviews or during field efforts on Pintlar Creek or the Big Hole River stream corridors.

Table 4-2: Select distribution statistics for overstory canopy density measured at streambanks on reference and impacted reaches of the Upper Big Hole River and Pintlar Creek.

Reach Type	N	Minimum	Maximum	25th percentile	Median	75th Percentile
			Big Hole River			
Reference	15	2	100	15	43	52
Impacted	30	0.00	100	0	1	15
			Pintlar Creek			
Pintlar Creek	5	0	92	45	56	72
Valley Reference Tributaries	40	0	100	36	64	81

4.1.1.4 Understory Shrub Cover along Green Line

Understory shrub cover along the green line (at bank full) is a measure of the proportion of 202 equidistant points along the streambanks that intercept shrubs from 0.5-3.0 meters in height. This method is a modification of the method developed by Winward (2000) with vegetation classes following EMAP methodologies developed by the EPA (Lazorchak et al. 1999). Shrub cover relates to thermal loading, as riparian shrubs are the primary cover type along the Big Hole River and Pintlar Creek below Pintlar Lake, with potential to provide substantial shading. Targets developed for this parameter are based on comparing the 25th percentile of the study stream to be greater than or approximate the 25th percentile of the reference conditions. Minor exceedences of the target value, or exceedences that are within statistical expectations, will result in little, if any, weighing toward determining if a TMDL is necessary while those with greater exceedence will be weighed more heavily. A higher canopy cover is desired; therefore, the 25th percentile is used for statistical comparison to reference condition. Comparison of median conditions may also be used to determine if a TMDL is necessary.

Several considerations played a role in the development of numeric targets from the reference reach data on the Big Hole River. First was the relatively low cover of understory shrubs in reference reach BH28. Field notes support the impacted status of riparian shrub cover in this reach was due to historic livestock grazing practices, which justified eliminating it from the statistical calculation of numeric targets for this parameter. In contrast, BH09 had exceptionally dense cover of riparian shrubs and no indication of livestock use. This relatively pristine state presents a potentially unfeasible scenario as ranchers often rely seasonally on riparian areas for thermal cover and high quality forage for livestock. Reference reach BH18 represented a scenario where BMPs were effectively utilized and, therefore, would meet the intent of Montana's Clean Water Act (CWA). Therefore, shrub cover on BH18 is a suitable reference for other reaches of the Big Hole River supporting livestock grazing uses. Using this site, the target for understory shrub cover along the green line will be for the 25th percentile to approximate or be more than 35 percent. Understory shrubs measured along the green line on valley reference tributaries provide the target for Pintlar Creek (**Table 4-3**). Following the approach as the Big Hole River, the target for Pintlar Creek will be for the 25th percentile to approximate or be less than 30 percent.

Table 4-3: Distributional statistics for understory shrub cover along the green line on reference and impacted reaches of the Big Hole River.

Reach Type	N	Minimum	Maximum	25th Percentile	Median	75th Percentile
Big Hole River						
reference (BH18)	4	32%	72%	37%	49%	63%
Impacted	24	0%	42%	4%	10%	23%
Pintlar Creek						
Pintlar Creek	8	37%	84%	42%	63%	81%
Valley reference tributaries	28	10%	85%	30%	59%	72%

4.1.1.5 Stream Flow

Stream flow is another factor with pronounced influence on thermal regime and is a major limiting factor for Arctic grayling in the Big Hole River. Irrigation withdrawals on Pintlar Creek also have potential to alter thermal regime. Pintlar Creek is periodically dewatered over much of its length (MFISH database). Reduced flows have less thermal inertia and therefore a greater tendency toward higher daily maximum temperatures.

Maintaining minimum flows in the Big Hole River is currently the focus of conservation efforts by landowners and agencies. To maintain consistency among planning efforts in the basin, targets for stream flow will incorporate those prescribed in the Candidate Conservation Agreement with Assurances (CCAA) (MFWP and USFWS 2005), but presenting only these flows as a target is not consistent with requirements of Montana's WQ law. Montana Law indicates that State recognized water rights can not be divested, impaired, or diminished due to application of water quality law. Meeting the CCAA and FWP instream flow targets may not always be possible while considering Montana's water laws and varying weather conditions. An alternative approach to meeting instream flows will be to apply all reasonable irrigation water management practices in the watershed that will increase instream flows without divesting, impairing, or diminishing any State recognized water right. Significant increases in stream flow can be accomplished by local irrigation water savings efforts which employ water saving engineering and management practices along with water leasing. Much of this type of work has already occurred during the past few years, and stream gage data reflect the efforts. To fully understand which irrigation water management practices are feasible, a more thorough water balance study should occur. Efforts should continue to expand application of all reasonable irrigation water management practices in the watershed which increase stream flow.

An approach to meeting instream flows that will reduce water temperature will be to meet the instream flow numeric targets based on the Candidate Conservation Agreements with Assurances (CCAA) for the Big Hole River and Montana FWP instream flow reservations (Pintlar Creek) **OR** apply all reasonable irrigation water management practices in the watershed that will increase instream flows without divesting, impairing, or diminishing any State recognized water rights. A brief rationale for the CCAA and Montana FWP instream flow reservations are provided below (**Table 4-4**).

Flow targets in the CCAA are provided to protect arctic grayling and use a reach based approach for prescribing minimum flows (**Table 4-4**). Thermal modeling efforts indicate that applying these instream flow conditions will have substantial influence on minimizing both mean daily and maximum daily temperatures on the Big Hole River (**Appendix B**). Currently, the only data available to evaluate target attainment are from the USGS gage station at the Wisdom Bridge. Montana FWP has installed AquaRod flow measuring devices at the other bridges and these data will be available for future TMDL target use. It is unknown if flow targets provided in the CCAA will be feasible by implementing all reasonable land, soil, and water conservation practices.

The FWP instream flow reservation is based on a wetted perimeter study which indicates a critical flow where riffles will stay wetted. It is unknown if flow targets provided by the FWP instream flow reservation will be feasible by implementing all reasonable land, soil, and water conservation practices.

Because of the uncertainty between the numeric stream flow targets and reasonable land, soil, and water conservation practices, an alternative to meeting flow targets is provided. Another option to meet instream flow targets indicates they can alternatively be met by implementing all reasonable irrigation water management practices in the watershed.

Table 4-4: Minimum flow targets for reaches within the Upper Big Hole River TPA in the CCAA.

CCAA Management Segment	Monitoring Site	Summer/Fall Minimum Flow Target (cfs)
A	Miner Creek Bridge	20
B	Little Lake Creek Bridge	40
C	Wisdom Bridge	60
D	Mudd Creek Bridge	100

Because of complications in access and the presence of significant beaver activity, considerable uncertainty exists regarding the relative role of dewatering on temperature regime in Pintlar Creek. The alternative is to apply FWP's reservation for instream flow as determined by the wetted perimeter method (Leathe and Nelson 1989). This calls for minimum flows of 10 cfs along the entire length of the stream below Pintlar Lake year round. An advantage to applying this target is constancy with existing fishery conservation recommendations for this stream. Nevertheless, the sufficiency of this flow volume to meet temperature WQS is unknown. Long-term monitoring and application of adaptive management will provide the means to evaluate the suitability of this target in supporting beneficial uses in Pintlar Creek. Pintlar Creek is identified by Montanan Fish, Wildlife, and Parks as periodically dewatered in the lowest 10 miles of the stream.

4.1.1.6 Linking Temperature to Fishery Impacts

Although Montana's temperature standards do not require a linkage of altered temperature conditions to an impacted use, this document will review the linkage. The potential for the Upper Big Hole River to support temperatures that are completely optimal for Arctic grayling (or the surrogate species, bull trout) is not fully known, but their presence suggests that the Upper Big Hole Valley historically supported conditions approximating Arctic grayling's optimal temperature needs. Although temperatures that are shown to support the fishery are not used specifically for targets because they don't directly relate to Montana's water quality temperature standards, they are useful for determining if the fishery is likely impacted by temperature conditions. These temperatures are also a consideration, along with other factors, for estimating naturally occurring conditions since native fish populations have survived in the watershed.

The thresholds used to determine if the fishery may be impacted are a maximum temperature of 64.4ºF (or 18ºC) because this temperature has the potential to physiologically impact grayling in a short timeframe. This temperature level is presented to protect against extreme physiological stress or lethal conditions. Optimal temperatures for bull trout, and potentially Arctic grayling, are between 10-12°C (50-54°F) with temperatures exceeding 59°F (15°C) resulting in sufficient physiological stress to inhibit growth (Fraley and Shepard 1989). Therefore, to promote a thermal regime favorable to growth of Arctic grayling, the sliding 7-day average of daily maximum temperatures is compared to a sublethal temperature stress target of 59°F (15°C). This document will use these fishery support temperature thresholds to indicate potential impacts to Arctic grayling, but will not use these thresholds as temperature targets because they do not relate to Montana's temperature standards.

4.1.1.7 Summary of Targets to Address Temperature in the Big Hole River

Targets developed to address temperature as a pollutant in the Big Hole River and Pintlar Creek consist of multiple lines of evidence (**Tables 4-5 and 4-6**). These include Montana's temperature standard, width-to-depth ratio, stream flow, and riparian vegetation shading characteristics. Combined, these measures provide a robust indication of the thermal setting and status of features that influence thermal loading.

Table 4-5: Numeric targets to address temperature loading in the Big Hole River.

Status	Target	Rationale	
Temperature monitoring and associated modeling indicates the standard is likely exceeded.	The maximum allowable increase over naturally occurring temperature (if the naturally occurring temperature is less than 67ºF) is 1°F and the rate of change cannot exceed 2°F per hour. If the natural occurring temperature is greater than 67ºF, the maximum allowable increase is 0.5ºF (ARM 17.30.622(e), ARM 17.30.623(e)).	Developed to protect all water uses, most notably, the fishery.	
Meet both temperature targets above OR meet all of the surrogate targets below.			
Width-to-depth ratio	75^{th} percentile ≤26 Median ≤22	Decreased surface area to volume ratio is less vulnerable to heating.	7 of 9 reaches not meeting target
Canopy Density Measured Over the Stream	25^{th} percentile ≥15% Median ≥43%	Shading from streamside vegetation is important functional attribute in maintaining cooler water temperatures.	3 of 9 reaches not meeting target
Understory Shrub Cover along Green Line	25^{th} percentile ≥37% Median ≥49%	Shading from streamside vegetation is important functional attribute in maintaining cooler water temperatures. Transpoevaporation also cools the stream corridor during heating periods.	2 of 9 reaches not meeting target
Instream Flow	>60 cfs at Wisdom gage *OR* apply all reasonable irrigation water management practices in the watershed that will increase instream flows without divesting, impairing or diminishing any State recognized water right.	Minimum summer survival flow prescribed in other grayling conservation efforts. More water in the stream provides thermal buffering capacity.	Flows not maintained

Table 4-5: Numeric targets to address temperature loading in the Big Hole River.

Status	Target	Rationale	
Irrigation Return Flows	Where irrigation return flows are occurring such that they are contributing to a measurable increase in temperature, the thermal loading will be reduced consistent with the irrigation water management BMPs that will be necessary to meet in-stream flow targets.	Reduce thermal loading.	Irrigation water return flows are present and likely vary in temperature. These were difficult to assess because they are transient in space and time.

Table 4-6: Numeric targets to address temperature loading in Pintlar Creek.

Parameter	Target	Rationale	Status (2004)
Water Quality Standard	The maximum allowable increase over naturally occurring temperature (if the naturally occurring temperature is less than 67ºF) is 1°F and the rate of change cannot exceed 2°F per hour. If the natural occurring temperature is greater than 67ºF, the maximum allowable increase is 0.5ºF (ARM 17.30.622(e), ARM 17.30.623(e)).	Developed to protect all water uses, most notably, the fishery.	Unknown
Meet both temperature targets above OR meet all of the surrogate targets below.			
Width-to-depth ratio	75^{th} percentile ≤20 Median ≤14	Decreased surface area to volume ratio is less vulnerable to heating.	Assessed reach met target Aerial photo interpretation of entire reach indicates high likelihood of meeting the target.
Canopy Density Measured Over the Stream	25^{th} Percentile ≥36% Median ≥64%	Shading from streamside vegetation is important functional attribute in maintaining cooler water temperatures.	Assessed reach met target. Aerial photo interpretation indicates high likelihood of meeting the target.

Table 4-6: Numeric targets to address temperature loading in Pintlar Creek.

Parameter	Target	Rationale	Status (2004)
Understory Shrub Cover along Green Line	25th percentile ≥30% Median ≥59%	Shading from streamside vegetation is important functional attribute in maintaining cooler water temperatures. Transpoevaporation also cools the stream corridor during heating periods.	Target met in assessed reach. Based on aerial photo interpretation, most reaches below Pintlar Lake are likely to approximate this target.
Instream Flow	≥10 cfs along entire stream below Pintlar Lake ***OR*** apply all reasonable irrigation water management practices in the watershed that will increase instream flows without divesting, impairing or diminishing any State recognized water right.	Minimum summer survival flow prescribed in other grayling conservation efforts. More water in the stream provides thermal buffering capacity.	Little to no stream guage data is available. A number of significant diversions are present.
Irrigation Return Flows	Where irrigation return flows are occurring such that they are contributing to a measurable increase in temperature, the thermal loading will be reduced consistent with the irrigation water management BMPs that will be necessary to meet in-stream flow targets.	Reduce thermal loading.	Irrigation water return flows are present and likely vary in temperature. These were difficult to assess because they are transient in space and time.

4.2 Sediment

Numeric targets and supplemental indicators for sediment are measures of instream siltation, factors that contribute to loading, storage and transport of sediment, or biological response to increased sediment. Other considerations in developing these targets include the natural variation in sediment storage along the river continuum. Specifically, some reaches will have a natural tendency for storage of sediment and others will be more efficient at sediment transport. Therefore, targets follow stratifications employed in data analysis. Stratification categories include the mainstem Big Hole River, North Fork Big Hole River, valley tributaries, and montane tributaries. Topographic breaks between the montane zone and foothills provided the basis for distinctions between montane and valley reaches. When appropriate, reaches on the North Fork Big Hole River were included with other tributary streams to increase statistical power. For parameters such as width-to-depth ratio, this was inappropriate, as the North Fork Big Hole River appeared to differ in potential channel geometry.

4.2.1 Sediment Targets

4.2.1.1 Width-to-depth Ratios

In addition to serving as a numeric target for temperature, width-to-depth ratio is also a suitable target for sediment TMDLs. Stream energy dynamics are shifted when stream channels are overly wide. Shifts in stream energy cause changes in sediment transport capacity, benthic sediment sorting, and pool formation. In addition, it relates directly to habitat quality as deeper, narrower channels provide superior fish habitat compared to wide, shallow streams. Moreover, a wide unstable channel is often a direct result of unstable banks that produce sediment. These links between width-to-depth ratio and sediment delivery and transport justify its inclusion as a numeric target. Evaluation of this method of quantifying width-to-depth ratio further suggests it is a reliable predictor of human disturbance (Kauffman et al. 1999). These factors decrease uncertainty in the use of this metric, an important consideration in its use as a numeric target. However, this target being exceeded alone, without other sediment target exceedences, does not constitute a need for a TMDL.

Valley gradient, valley confinement, riparian vegetation types, and watershed areas are natural factors that affect stream channel width and depth (**Table 4-7**). For example, using the Rosgen channel classification system (Rosgen 1996), A, DA, and E channels have relatively low width-to-depth ratios of 12 or less. Conversely, C channels tend to have greater width-to-depth ratios (>12). To adjust for these tendencies, streams were stratified into four classifications: Mainstem Big Hole River, valley tributaries, montane tributaries, and North Fork Big Hole River. This stratification takes into account valley slope and width, stream size, and riparian vegetation type that are the most significant factors affecting stream channel characteristics. Montane reaches tended to break out among three channel types with B channels occupying steeper valley types, and E and C channels occurring in lower gradient montane valley reaches. Because B channels tend to be resistant to lateral and vertical instability in the Upper Big Hole TPA, montane B channels were eliminated from this analysis and width-to-depth ratio target development.

Table 4-7: Channel types (Rosgen 1996) identified on streams in the Upper Big Hole River Watershed in Level I classification activities and verified with field investigations.

Stream Type (w:d ratios)	Fundamental Characteristics
A (<12)	A-Type Channels are relatively steep channels that form in headwater areas as well as within bedrock canyons. These channels are entrenched and confined by steep valley margins such that little to no floodplain occurs on their border. As the boundaries of A-type channels are typically highly resistant to erosion, these stream types are generally quite resilient with respect to human impacts. The most common cause of geomorphic change within A-type channels is due to large scale sediment transport events, (landslides, debris flows, debris jam failure) that may result in blockage or deflection of channel flow.
B (>12)	B-Type Channels tend to form downstream of headwater channels, in areas of moderate slope where the watershed transitions from headwater environments to valley bottoms. Moderate slopes, moderate entrenchment, and stable channel boundaries characterize B-channels. Due to the relatively steep channel slopes and stable channel boundaries, B-channels are moderately resistant to human impacts, although, their reduced slopes relative to headwater areas can make them prone to sediment deposition and subsequent adjustment in the event of a large sediment transport event such as an upstream landslide, debris flow, or flood.
C (>12)	C-Type Channels are typically characterized by relatively low slopes, meandering plan forms, and pool/riffle sequences. The channels tend to occur in broad alluvial valleys, and they are typically associated with broad floodplain areas. C-channels tend to be relatively sinuous, as they follow a meandering course within a single channel thread. In stream systems in which the boundaries of C-type channels are composed of alluvial sediments, channels tend to dynamic in nature, and susceptible to rapid adjustment in response to disturbance.
DA (<40)	DA-Type Channels have multiple active channel threads that are relatively narrow and deep, separated by extensive, vegetated floodplains and wetlands. DA channels tend to form in areas of relatively low slope, with low bedload sediment volumes. Bank lines are typically very stable.
E (<12)	E-Type Channels are somewhat similar to C channels, as they form as single threads with defined, accessible floodplain areas. However, E channels are different in that they tend to have fine-grained channel margins, which provide cohesion and support dense bank line vegetation. The fine-grained, vegetation-reinforced bank lines allow for the development of steep banks, very sinuous plan forms, and relatively deep, U-shaped channel cross sections. E-type channels commonly form in low gradient areas with fine-grained source areas, mountain meadows, and in beaver-dominated environments. E-channels tend to have very stable plan forms, and efficient sediment transport capacities due to low width/depth ratios.
F (>12)	F-Type Channels typically have relatively low slopes (<2%), similar to C and E channel types. The primary difference between C/E channels and F channels is with respect to entrenchment. F channels are entrenched, which means that the floodplain is quite narrow relative to the channel width. The entrenchment of alluvial F-type channels typically is an indicator of an historic down cutting event. F-type channels may form in resistant boundary materials (e.g. U-shaped bedrock canyons), and relatively erodible alluvial materials (e.g. arroyos). When the boundary materials are erodible, the steep valley walls are prone to instability, and channel widening commonly occurs within the entrenched channel cross section.

A Rosgen level I channel classification followed by field verification allowed classification of channel types across the Upper Big Hole River TPA. On the Big Hole River, channel types varied among assessed reaches with a tendency for reference reaches to have braided channels, (Rosgen DA), interspersed with C channel types (**Table 4-8**). These DA channels are highly desirable in terms of having low width-to-depth ratios and providing superior habitat for Arctic grayling, a species preferring low gradient, braided rivers. With the exception of reach BH08, impacted reaches were typically C channels. The maintenance of the DA configuration to the lowermost reference reach suggested targets based on reference reaches with a tendency for braiding was appropriate for the entire length of Big Hole River in this TPA.

Table 4-8: Rosgen channel types of assessed reaches on the Big Hole River.

Reach Name	Reach Type	Stream Type
BH09	Reference	DA
BH18	Reference	C/DA
BH28	Reference	C/DA
BH08	Impacted	C/E
BH16	Impacted	C
BH22	Impacted	C
BH26	Impacted	C

Channel types on valley tributaries tended towards C and E channels with many reaches being transitional between these types (**Table 4-9**). Reference reaches had a greater tendency to be E channels, except for the reference reaches on the North Fork Big Hole River, which were C channels. The prevalence of C/E transitional channels in the smaller valley reference tributaries justifies the application of width-to-depth ratio targets from these reference areas. Therefore, targets for width-to-depth ratio will vary with an internal reference applied to the North Fork Big Hole River and other valley tributaries will follow distributional statistics from valley reference tributaries.

Table 4-9: Channel type classifications of assessed valley reaches in Upper Big Hole River TPA.

Stream Name	Reach Name	Stream Type	Reach Type
Doolittle	DC03	E/C	impacted
Fox	FC03	E	reference
Fox	FC02	E	impacted
Governor	GC04	C	impacted
Governor	GC06	C	impacted
Governor	GC11	C	impacted
Johnson	JC07	C	impacted
Little Lake	LL05	E	reference
McVey	MV03	E	impacted
Miner	MC05	E	reference
Mussigbrod	MC06	C/E	reference
Mussigbrod	MC07	E	impacted
North Fork	NF02	C	reference
North Fork	NF06	C	reference
North Fork	NF07	C	impacted
North Fork	NF11	C	impacted

Table 4-9: Channel type classifications of assessed valley reaches in Upper Big Hole River TPA.

Stream Name	Reach Name	Stream Type	Reach Type
Pine	PN03	C/E	impacted
Pintlar	PC04	C/E	reference
Pintlar	PC04R	C/E	reference
Rock	RO04	C	impacted
Rock	RO06	C	impacted
Ruby	RC07	E/C	impacted
Ruby	RC08	E/C	impacted
Steel	SC06	C/D	impacted
Steel	SC03	E	impacted
Swamp	SW03	E	impacted
Swamp	SW10	C	impacted
Warm Springs	WS11	C/E	impacted
Warm Springs	WS10	C/E	impacted

Channel types on montane reaches were variable with B, C, and E channel types being present (**Table 4-10**). Most reference reaches occupying low gradient, meadow sections were narrow, deep E channels. The B channels occurred in higher gradient reaches. The exception was the reference reach on Warm Springs Creek (WS07), which classified as a C channel. Field notes suggest that livestock grazing practices contributed to channel widening in this reach, making it marginal in terms of reference reach status. As a result, it was eliminated from the pool of reference reaches for segments occupying montane meadows.

Table 4-10: Channel type classifications of assessed montane tributary reaches in Upper Big Hole River TPA.

Stream Name	Reach Name	Stream Type	Reach Type
Frances	FR01	C	impacted
Johnson	JC03	B	reference
Johnson	JC02	B	impacted
Johnson	JC02R	B	impacted
Joseph	JO02	C	impacted
Ruby	RC04	E	impacted
Schultz	SH01	B	reference
Steel	SC02	E	reference
Tie	TI02	E	impacted
Trail	TC02	E	reference
Trail	TC07	E	reference
Trail	TC03	E	impacted
Trail	TC08	B	impacted
Warm Springs	WS07	C	impacted

The width-to-depth depth ratio targets for the mainstem of the Big Hole River for the sediment TMDL will be the same as those designated to address thermal alterations (**Section 1.1.1** and

Table 4-1). Reducing width-to-depth ratios to approximate those measured in reference reaches will improve sediment transport capabilities and may reduce accumulations of fine sediment on the streambed. Therefore, the width-to depth target to address sediment in the Big Hole River was for the 75^{th} percentile to approximate or be less than 30 (**Table 4-11**). Minor exceedences of the target value, or exceedences that are within statistical expectations, will result in little, if any, weighing toward determining if a TMDL is necessary, while those with greater exceedence will be weighed more heavily. This target would account for a range of potential Rosgen channel types including C, DA, and E.

Using the same rationale as the Big Hole River for montane tributaries, valley tributaries, and the North Fork Big Hole River, the numeric target for width-to-depth ratios will be for the 75^{th} percentile to approximate or be less than the 75^{th} percentile of reference reaches for the appropriate stratification (**Table 4-11**). The target for montane reaches occupying higher gradient B channels will be for the 75^{th} percentile to approximate or be less than 16. On montane reaches within low gradient, meadow environments, the 75^{th} percentile will be to approximate or be less than 14. Because reference reaches on the North Fork Big Hole River were C channels, the width-to-depth ratio for this stream reflects morphology typical of stable C channels, but well below thresholds for “very high width-to-depth ratios” as ranked by Rosgen (1996) with the 75^{th} percentile being to approximate or be less than 30. Finally, the target established for valley tributaries follows the same approach. Therefore, the target for valley tributaries calls for the 75^{th} percentile to approximate or be less than 17.

The width-to-depth ratios reported for the Upper Big Hole TMDL project are collected at set intervals along a reach of stream and may fall at any type of stream channel area. These width-to-depth ratios are representative of cumulative widths measures, but not comparable to with-to-depth ratios collected only at riffle cross sections.

Table 4-11: Distributional statistics for cumulative width-to-depth ratios measured on reference reaches on montane tributaries, valley tributaries, the North Fork Big Hole River, and the mainstem Big Hole River.

Stream Classification	N	Minimum	Maximum	25th Percentile	Median	75th Percentile
Montane Tributaries (high gradient channels)	10	6	42	8	13	15
Montane Tributaries (low gradient channels)	10	4	16	8	10	13
Valley Tributaries	39	5	32	10	14	19
North Fork Big Hole River	10	10	30	17	24	28
Big Hole River	15	8	43	21	22	26

4.2.1.2 Percent Fines (Pebble Counts)

Pebble counts are a common method to quantify size class distribution of streambed particles in gravel bed streams (Wolman 1954) with applications to sediment transport, hydraulics, and streambed monitoring. Pebble counts in this effort used the 100-particle count in riffles, which is a standard method for surface particles (Bunte and Abt 2001).

Benthic measurements of fine sediment are a direct measurement of sediment conditions and relate directly to aquatic life and fisheries uses. Accumulations of fine substrate particles fill the interstices of coarser bed materials, reducing habitat space and its availability for benthic fish and macroinvertebrates (Platts et al. 1983; Hawkins et al., 1983; Rinne, 1988; Waters, 1995; Mebane, 2001, Zweig et al., 2001; Reylea et al., 2000). In addition, these fine particles impede circulation of oxygenated water into hyporheic habitats. Not meeting this target suggests fine sediment is likely impacting aquatic life and cold water fish.

Targets will be set by comparing median reference conditions to data from impacted areas (**Tables 4-12 and 4-13**). A minimum of 10 percent fines in riffles will be used for targets if the median reference condition falls below this level. Using a minimum of 10 percent is based upon the fact that studies show a marked impact to aquatic life begins to occur at specific levels of fine sediment in riffles and 10 percent falls below this threshold, yet it preserves the setting where low fine sediment is expected with reasonable watershed management (Rylea et al, 2000). Also, as broadcast spawning fish, grayling may rely on lower ends of riffles, as well as runs, for spawning activity and may warrant percent fines targets set in riffle areas that is more protective than for other species utilizing this habitat area.

Table 4-12: Distributional statistics of percent particles <6 mm in 100-particle pebble counts on reference reaches (not watersheds).

	Minimum	Maximum	25th Percentile	Median	75th Percentile
Big Hole River	0	11	0	0	5
North Fork Big Hole River	7	16	9	12	14
Valley Tributary	1	41	16	22	30
Montane Tributary	11	44	13	17	27

Table 4-13: Distributional statistics of percent particles <2 mm in 100-particle pebble counts on reference reaches (not watersheds).

	Minimum	Maximum	25th Percentile	Median	75th Percentile
Big Hole mainstem	0	8	0	0	4
North Fork	5	14	7	10	14
Valley tributaries	1	38	12	18	20
Montane	4	32	4	13	22

4.2.1.3 Percent Fines (Viewing Bucket)

Sampling surface fines with a 49-point grid is another common method of quantifying fine particles on streambed surfaces (Platts et al. 1987, Hankin and Reeves 1988, Overton et al. 1997). In field assessments of 2004, crews employed a 49-point grid on Plexiglas bottomed viewing buckets at four locations across each pool tail. This is a measure of the number of grid intersections underlain by at least one particle less than 6 mm in diameter and is expressed as a percentage for each pool tail. Pool tails were the selected channel unit type, as these are typically preferred spawning areas for most salmonids, excluding Arctic grayling. Applicability of this assessment technique to species such as Arctic grayling is uncertain. Cutthroat trout are likely the most sensitive species to siltation effects in this area. Westslope cutthroat trout are, or have been, present in most of the streams of the Upper Big Hole Valley and are likely the most siltation sensitive fish species present.

Percent fines in reference reaches varied with highest levels occurring in valley tributaries (**Table 4-14**). Median values will be used for target comparison. With the exception of valley tributaries, median reference values were less than 30 percent. In contrast, median values in valley tributary streams exceeded 80 percent fines. This suggests that high levels of fine sediment were somewhat natural in these low gradient streams or that sediment loading from the watershed above the reference reaches overwhelmed the ability of these reaches to transport sediment. The reference reaches do not represent a reference watershed condition, but do represent areas where the appropriate land management supports a stream channel with dimensions for efficient sediment transport and sorting. Because reference sites are used instead of reference watersheds, the median of the internal reference conditions is used as a target threshold, and any exceedence of the target is considered grounds for TMDL development. If the threshold is approached with other indicators of sediment condition departure, the stream may also be considered for TMDL development since most streams in this area are not considered to be near reference condition except for Miner and Little Lake Creek watersheds.

Table 4-14: Distributional statistics of percent particles <6 mm sampled using 49-point grids in reference reaches in the Upper Big Hole River TPA.

Classification	N (pool tail)	Minimum	Maximum	25th Percentile	Median	75th Percentile
Big Hole River	14	3	100	10	22	57
Montane (high gradient)	15	0	100	5	10	42
Montane (low gradient)	9	13	100	42	50	92
North Fork Big Hole River	3	11	38	11	11	24
Valley	36	10	100	27	80	95

4.2.1.4 Pool Frequency

Pool frequency is another parameter allowing inference on the influence of sediment in streams. Alterations in sediment loading or sediment transport efficiency may have deleterious effects on this important component of fish habitat, thereby decreasing the stream’s ability to support this beneficial use. Sediment may limit pool habitat by filling in pools with fines. Alternatively, aggradation of larger particles may exceed the stream’s capacity to scour pools, thereby reducing the prevalence of this critical habitat feature. Therefore, pool frequency is a measure that potentially responds to both fine and larger fractions of sediment delivered to the stream and addresses transport efficiencies related to alterations in flow and channel geometry.

Comparing expected pool frequency with existing pool frequency provides a means of evaluating sediment transport dynamics and habitat quality relating to sediment. Two ways allow prediction of expected pool frequency for a given reach. One rule of thumb is that in unaltered streams, pools occur on average at every 5-7 channel widths (Dunne and Leopold 1978, Rosgen 1996). Alternatively, reference reaches provide a means of predicting pool frequency based on the assumption that these reaches represent the potential pool frequency as pool forming features, such as woody debris and channel geometry are intact.

Several natural factors have potential to influence pool frequency, and these need to be included in interpretations. One factor is channel type as influenced by gradient, topography, and bed material. Streams occupying higher gradient, confined reaches with boulder or bedrock substrate have less potential to scour pools than more meandering valley reaches with finer bed materials. To control for these factors, B channels in montane portions of the watershed were eliminated from the suite of reference reaches used in the calculation or application of this target.

Analyses of reference reach data indicates these reaches had pool frequencies close to the expected for unaltered streams, namely, a pool occurred for every 5-7 channel widths (**Table 4-15**). To control for variability in channel widths, these values are expressed as a function of the average number of median bankfull widths between pools. These results suggest sediment loading and transport was in balance to support adult fish habitat requirements in reference reaches.

Table 4-15: Distributional statistics for bankfull width per pool measured on reference reaches in the Upper Big Hole River TPA.

Classification	N	Minimum	Maximum	25th Percentile	Median	75th Percentile
Big Hole River	3	3.0	5.6	3.9	4.7	5.1
Valley Tributaries + NF	7	4.7	21.8	5.2	7.3	8.4
Montane C and E channels	2	2.8	6.0	5.1	5.4	5.7

Unlike many of the parameters used as targets and supplemental indicators, only one result per assessed reach is possible for this parameter, yet many measures are incorporated into the result. The bankfull width to pool frequency target will be ≤ the designated 75^{th} percentile of the reference data set. These values are consistent with the typical values for meandering streams and account for the potential for reaches occupying various locations in the watershed.

4.2.1.5 Understory Shrub Cover along the Green Line

The proportion of riparian shrubs along the bankfull margin or green line provides another target to address siltation in the Upper Big Hole River TPA. Shrubs promote structural stability of banks through their massive, deep root systems (Beschta 1991). During flooding events, shrubs form protective mats over banks, which dissipate flow velocities and permit the transported sediments to settle out, thereby building banks and providing fertile soils (Platts and Rinne 1985). During winter months, vegetative cover promotes bank stability by insulating banks and reducing ice formation in the soil, which reduces heaving and erosion (Bohn 1989). Together, the functional attributes of maintaining bank stability and filtering sediments result in reduced delivery of sediment to surface waters. Understory shrub cover along bank full margins can be applied for use in the sediment target weight of evidence approach with relatively high certainty. As described above, this parameter has direct relevance to near stream sediment production.

Percent shrub cover along the green line showed considerable similarity among reference reaches on the Big Hole River, North Fork Big Hole River, and valley tributaries (**Table 4-16**). Shrub cover was less on montane tributaries, because conifer trees were a more significant component along some of the forested reaches. However, most reaches assessed in forested environments had potential for riparian shrub community with a few exceptions. This target will not be applied to the exceptions where conifers were dominant in riparian zones. The target is for the 25th percentile of percent shrub cover to approximate or be more than the 25th percentile of the reference reaches. Minor exceedences of the target value, or exceedences that are within statistical expectations, will result in little, if any, weighing toward determining if a TMDL is necessary, while those with greater exceedence will be weighed more heavily. The 25th percentile of the reference population is used as a comparative statistic because a higher amount of understory along the bank of streams is desired. Although the 25th percentile will be used as a target, the overall quartiles may be used to assess stream conditions along with an aerial photo review of the entire stream corridor. Median conditions may also be used to determine if a TMDL is necessary when considered in a multiple line of sediment impact approach with other targets.

Table 4-16: Distributional statistics for percent understory shrub cover on streambanks measured on reference reaches on montane tributaries, valley tributaries, and the North Fork Big Hole River.

Stream Classification	N	Minimum	Maximum	25th Percentile	Median	75th Percentile
Big Hole River	12	10	86	31	50	73
North Fork	8	24	62	35	41	51
Valley Tributaries	28	10	84	32	58	72
Montane Tributaries (C and E Channels)	12	26	80	36	41	73

4.2.2 Supplemental Indicators for Sediment

4.2.2.1 Eroding Banks

Extent and severity of bank erosion presents an indicator to address siltation in streams in the Upper Big Hole River TPA. Eroding banks are often a significant source of sediment to streams. Although bank erosion is a natural process along streams, land use practices that reduce riparian vegetation and result in mechanical damage to banks can accelerate this natural process and directly contribute sediment to the stream system.

Field assessments in 2004 included a survey of visually eroding banks within each 1000-foot study site. Evaluations included measurements of the length and height of eroding banks and completion of a questionnaire geared at evaluating severity of erosion per bank. Note that only one value of this measure occurs per assessment reach, unlike some of the other measures used for targets and indicators.

Visually eroding banks were a relatively rare feature on reference reaches in the Upper Big Hole River TPA (**Table 4-17**). Median area of eroding bank ranged from 47-148 ft^2 on reference reaches depending on stream classifications based for target setting. Bank erosion composed less than 10 percent of the streambank length on most reference reaches. The target for bank erosion on the Big Hole River mainstem calls for the 75th percentile of any assessed reach's bank erosion to approximate or be less than the 75th percentile for the reference reaches. Minor exceedences of the target value, or exceedences that are within statistical expectations, will result in little, if any, weighing toward determining if a TMDL is necessary, while those with greater exceedence will be weighed more heavily. The 75th percentile of the reference population is used as a comparative statistic because accelerated bank erosion rates are undesirable. Median conditions may also be assessed to help compare reference condition to the stream of concern.

Table 4-17: Distributional statistics for area of eroding banks (ft^2) measured on reference reaches in the Upper Big Hole River TPA.

Classification	N	Minimum	Maximum	25th Percentile	Median	75th Percentile
Big Hole River	2	148	493	0	320	406
Montane Streams	4	36	243	0	53	113
Valley Streams*	6	31	297	0	118	212

* Valley streams include North Fork Big Hole River, as reference values were similar to other reference valley reference reaches.

4.2.2.2 Macroinvertebrate Bioassessment Score

Siltation exerts a direct influence on benthic macroinvertebrates assemblages through several mechanisms. These include limiting preferred habitat for some taxa by filling in interstices or spaces between gravel. In other cases, fine sediment limits attachment sites for taxa that affix to substrate particles. Macroinvertebrate assemblages respond predictably to siltation with a shift in natural or expected taxa to a prevalence of sediment tolerant taxa over those that require clean gravel substrates. Macroinvertebrate bioassessments scores are an assessment of the macroinvertebrate assemblage at a site, and are used by the DEQ to evaluate impairment condition and beneficial use support during the 303(d) Listing process (the assessment in this document is not the 303(d) Listing process). The advantage to these bioindicators is that they provide a measure of support of associated aquatic life, an established beneficial use of Montana's waters.

In 2006, Montana DEQ adopted impairment thresholds for bioassessment scores based on two separate methodologies. The **Multi-Metric Index (MMI)** method assesses biologic integrity of a sample based on a battery of individual biometrics. The **River Invertebrate Prediction and Classification System (RIVPACS)** method utilizes a probabilistic model based on the taxa assemblage that would be expected at a similar reference site. Based on these tools, the DEQ adopted bioassessment thresholds that were reflective of conditions that supported a diverse and biologically unimpaired macroinvertebrate assemblage, and therefore a direct indication of beneficial use support for aquatic life.

The MMI is organized based on the different ecoregions within Montana. Three MMIs are used to represent the various Montana ecoregions: Mountain, Low Valley, and Plains. Each region has specific bioassessment threshold criteria that represent full support of macroinvertebrate aquatic life uses. The Big Hole Watershed falls within both Mountain and Low Valley MMI regions. The MMI score is based upon the average of a variety of individual metric scores. The metric scores measure predictable attributes of benthic macroinvertebrate communities to make inferences regarding aquatic life condition when pollution or pollutants affect stream systems and instream biota.

The RIVPACS model compares the taxa that are expected at a site under a variety of environmental conditions with the actual taxa that were found when the site was sampled. The RIVPACS model provides a single dimensionless ratio to infer the health of the macroinvertebrate community. This ratio is referred to as the Observed/Expected (O/E) value. Used in combination, the results suggest strong evidence that a waterbody is either supporting or non-supporting its aquatic life uses for aquatic invertebrates.

Basis for Target Values

For the Multi-Metric Index, individual metric scores are averaged to obtain the final MMI score. The score will range between 0 and 100. **The impairment thresholds are 63 and 48 for the mountain and low valley indices, respectively.** The impairment threshold (10^{th} percentile of the reference dataset) represents the point where DEQ technical staff believed macroinvertebrates are affected by some kind of impairment (e.g. loss of sensitive taxa).

The RIVPACS impairment threshold for all Montana streams is any O/E value <0.8. However, the RIVPACS model has a bidirectional response to nutrient impairment. Some stressors cause macroinvertebrate populations to decrease right away (e.g. metals contamination) which causes the score to decrease below the impairment threshold of 0.8. Nutrient enrichment may actually increase the macroinvertebrate population diversity before eventually decreasing below 0.8. An upper limit was set to flag these situations. The 90^{th} percentile of the reference dataset was selected (1.2) to account for these situations, and any value above this score is defined as impaired unless specific circumstances can justify otherwise. However, RIVPACS scores >1.0 are considered unimpaired for all other stressor types.

Most scores significantly below the RIVPACS and MMI impairment thresholds are impaired. Some model scores may be close to the threshold. These sites may be considered unimpaired in some situations. For example, a site classified in the Mountain ecoregion may have a mountain MMI score of 83, well above the mountain MMI threshold (63), and a RIVPACS score of 0.76, close to the RIVPACS impairment threshold (0.8). The assessor may determine that the macroinvertebrate community at the site is unimpaired. Ultimately, the assessor will determine the degree of impairment (i.e. moderate or severe) using best professional judgment and guidance found in the State’s bioassessment process (DEQ, 2006). These values will also be used for targets in this document, but do not necessarily indicate that sediment is the cause of the impacted macro invertebrate community. These metrics need to be considered along with physical sediment and stream channel data.

4.2.3 Sediment Target and Supplemental Indicator Summary

The following **Tables 4-18 through 4-22** summarize sediment targets and supplemental indicators for each of the distinctly different stream categories found in the Upper Big Hole Watershed. The categories include the mainstem of the Big Hole River, the North Fork of the Big Hole River, valley bottom tributaries, and montane tributaries.

Table 4-18: Targets and supplemental indicators to address sediment in the upper Big Hole River (above Doolittle Creek).

Parameter	Target	Rationale
	Targets	
Width-to-depth ratio	75th Percentile ≤26 Median ≤ 22	Streams with the appropriate width-to-depth ratio transport and sort sediment more efficiently.
Understory Shrub Cover along Green Line	25th Percentile ≥35%	Shrubs function to maintain bank stability, reduce in channel sediment sources and filter sediments.
Pool Frequency (# of Bankfull Widths between pools)	≤5.55	Indicates if fine or larger sized sediment transport dynamics or supply is excessive and indicates if fish habitat is impacted by pool filling.
Percent Fines < 6 mm (Viewing Bucket)	Median ≤22%	Indicates if fine sediment supply is impacting salmonid fish spawning success.
Percent Fines < 2 or 6mm (Pebble Counts)	Median ≤10%	Indicates if fine sediment supply is likely impacting macroinvertebrates or broadcast fish spawning success.
	Supplemental Indicators	
Human Caused Sources	Significant human caused sources have to be present.	If no significant human caused sediment yield or transport changes are present in a watershed, restoration practices can not reduce sediment loads. A TMDL is not necessary for naturally occurring sources.
Macroinvertebrate Bioassessment	Mountain MMI >63 Valley MMI >48 1.2>RIVPACS>0.80	Macroinvertebrates are a direct measure of beneficial use.
Eroding Banks	75th Percentile ≤493	Eroding banks are a significant source of sediment

Table 4-19: Targets and supplemental indicators to address sediment pollution in the North Fork Big Hole River

Parameter	**Target**	**Rationale**
	Targets	
Width-to-depth ratio	75^{th} Percentile ≤28 Median ≤ 24	Streams with the appropriate width-to-depth ratio transport and sort sediment more efficiently.
Understory Shrub Cover along Green Line	25^{th} Percentile ≥35%	Shrubs function to maintain bank stability, reduce in channel sediment sources and filter sediments.
Pool Frequency (# of Bankfull Widths between pools)	≤7.93	Indicates if fine or larger sized sediment transport dynamics or supply is excessive and indicates if fish habitat is impacted by pool filling.
Percent Fines < 6 mm (Viewing Bucket)	Median ≤11%	Indicates if fine sediment supply is impacting salmonid fish spawning success.
Percent Fines < 2mm (Pebble Counts)	Median ≤10%	Indicates if fine sediment supply is likely impacting macroinvertebrates or broadcast fish spawning success.
	Supplemental Indicators	
Human Caused Sources	Significant human caused sources have to be present.	If no significant human caused sediment yield or transport changes are present in a watershed, restoration practices can not reduce sediment loads. A TMDL is not necessary for naturally occurring sources.
Macroinvertebrate Bioassessment	Mountain MMI >63 Valley MMI >48 1.2>RIVPACS>0.80	Macroinvertebrates are a direct measure of beneficial use.
Eroding Banks	75^{th} Percentile ≤176	Eroding banks are a significant source of sediment

Table 4-20: Targets and supplemental indicators to address sediment in the valley tributaries in the Upper Big Hole River TPA.

Parameter	Threshold	Rationale
	Targets	
Width-to-depth ratio	75^{th} Percentile ≤19 Median ≤14	Streams with the appropriate width-to-depth ratio transport and sort sediment more efficiently.
Understory Shrub Cover along Green Line	25^{th} Percentile ≥30%	Shrubs function to maintain bank stability, reduce in channel sediment sources and filter sediments.
Pool Frequency (# of Bankfull Widths between pools)	≤7.93	Indicates if fine or larger sized sediment transport dynamics or supply is excessive and indicates if fish habitat is impacted by pool filling.
Percent Fines < 6 mm (Viewing Bucket)	Median ≤80%	Indicates if fine sediment supply is impacting salmonid fish spawning success.
Percent Fines < 2mm (Pebble Counts)	Median ≤18%	Indicates if fine sediment supply is likely impacting macroinvertebrates or broadcast fish spawning success.
	Supplemental Indicators	
Human Caused Sources	Significant human caused sediment production or transport impacts are present.	If no significant human caused sediment yield or transport changes are present in a watershed, restoration practices can not reduce sediment loads. A TMDL is not necessary for naturally occurring sources.
Macroinvertebrate Bioassessment	Mountain MMI >63 Valley MMI >48 1.2>RIVPACS>0.80	Macroinvertebrates are a direct measure of beneficial use.
Eroding Banks	75^{th} Percentile ≤176	Eroding banks are a significant source of sediment

Table 4-21: Targets and supplemental indicators to address sediment in the montane tributaries in the Upper Big Hole River TPA.

Parameter	Threshold	Rationale
	Targets	
Width-to-depth ratio	75th Percentile ≤15 Median ≤13 in high gradient channels 75th Percentile ≤13 Median ≤10 in low gradient channels	Streams with the appropriate width-to-depth ratio transport and sort sediment more efficiently.
Understory Shrub Cover along Green Line	25th Percentile ≥30%	Shrubs function to maintain bank stability, reduce in channel sediment sources and filter sediments.
Pool Frequency	≤6.61 in C and E channels	Indicates if fine or larger sized sediment transport dynamics or supply is excessive and indicates if fish habitat is impacted by pool filling.
Percent Fines < 6 mm (Viewing Bucket)	High gradient - Median ≤10% Low gradient Median ≤50%	Indicates if fine sediment supply is impacting salmonid fish spawning success.
Percent Fines < 2mm (Pebble Counts)	Median ≤13%	Indicates if fine sediment supply is likely impacting macroinvertebrates or broadcast fish spawning success.
	Supplemental Indicators	
Human Caused Sources	Significant human caused sediment production or transport impacts are present.	If no significant human caused sediment yield or transport changes are present in a watershed, restoration practices can not reduce sediment loads. A TMDL is not necessary for naturally occurring sources.
Macroinvertebrate Bioassessment	Mountain MMI >63 Valley MMI >48 1.2>RIVPACS>0.80	Macroinvertebrates are a direct measure of beneficial use but these metrics don't directly relate to sediment so they must be used along side sediment data.
Eroding Banks	75th Percentile ≤200	Eroding banks are a significant source of sediment

4.3 Nutrients

Targets and supplemental indicators for nutrients are based upon interpretation of Montana's narrative water quality standards. Montana's water quality standards for nutrients are addressed via the narrative criteria identified in **Section 3.3.2.1**. These narrative criteria do not allow for "*substances attributable municipal, industrial, agricultural practices or other discharges that will...(e) create conditions which will produce undesirable aquatic life*", ARM 17.30.637.

Nutrient targets include direct measures of nutrient concentrations in surface waters, measures of benthic chlorophyll *a* concentrations, and the role of riparian vegetation in mitigating nutrient loading through uptake and filtering. Dissolved oxygen levels may indicate a nutrient impairment condition that may limit fish and aquatic life growth and may be used as supplemental information if available. In addition, biological assemblages may provide several indicators of nutrient enrichment.

Framework Nutrient TMDLs

It is acknowledged that existing nutrient data for the Upper – North Fork Big Hole TPA is limited and targets are based on a numeric translation of Montana's narrative nutrient standards. As a result, the level of certainty associated with the nutrient targets and existing condition review may be low depending upon water body, and upon potential adoption of numeric nutrient standards in the future, may need to be revised. The nutrient targets are considered interim values that may need to be revised in the future and compliance with the targets is currently considered voluntary. An adaptive management strategy to facilitate revision of the nutrient targets, TMDLs, and allocations is presented in **Section 9.0**.

4.3.1 Nutrient Concentrations and Chlorophyll a

The Big Hole River and its tributaries are mostly located in the Middle Rockies ecoregion. The most sensitive uses are those associated with fisheries and aquatic life uses. If these uses are protected, drinking water and agriculture uses will also be protected. The standard relative to fisheries and aquatic life prohibit "conditions which produce undesirable aquatic life" (ARM 17.30.637). The narrative standard does not define what undesirable aquatic life is, nor does it provide nutrient concentrations appropriate to control it. In response to EPA's directive to states to develop numeric nutrient criteria, Montana submitted a nutrient plan to EPA in 2002 detailing how they will determine which beneficial uses are impacted, how undesirable aquatic life will be defined, and how numeric nutrient criteria will be developed. Since 2002, Montana has conducted a number of technical studies and is pursuing development of numeric criteria for nutrients.

In the interim, to facilitate a measurable comparison of ambient water quality data with the narrative standards and to establish end-point nutrient goals for the TMDLs, indicators of nutrient impairment and threshold values have been selected based on the results of the work that Montana has completed to date in an effort to ultimately develop numeric nutrient criteria (Suplee *et. al*., 2007; Suplee, 2006; Suplee, 2005). These nutrient investigations are used for setting nutrient and chlorophyll *a* interim targets along with riparian vegetation studies within the Big Hole Watershed that are used for justifying supplemental indicators for nutrients. The interim targets and associated indicator values provided in this document are not water quality standards. Rather, they are considered interim values subject to modification in the future following the adaptive management strategy presented in **Section 9.0.**

The selected interim targets for Upper – North Fork TPA include total phosphorus (TP), total nitrogen (TN), and benthic chlorophyll-*a*. Interim threshold values for the nutrient parameters are presented in **Table 4-22**. These are growing season, or summer, values applied from July 1st through September 30th.

Table 4-22: Interim Nutrient Targets

Parameter	Concentration
Total Phosphorus	0.049 mg/l
Total Nitrogen	0.320 mg/l
Maximum Benthic Chlorophyll-*a*	150 mg/m2

When evaluating compliance with these goals it is important to consider that high levels of phosphorous or nitrogen loading to a stream might not show up as elevated concentrations in the water column, particularly during growing season. This is because nutrient uptake by growing algae could occur to the extent that nutrient concentrations in the water column are significantly reduced within a given length of stream. Therefore, it is important to measure algae concentrations, represented by benthic chlorophyll a, at the same time that nutrient concentrations are being measured to provide an adequate characterization of water quality conditions. When subsequently evaluating compliance with the above endpoint goals, it is important to first evaluate compliance with the chlorophyll a values before drawing conclusions regarding compliance with either the total phosphorous or total nitrogen concentration values. Furthermore, the interim total phosphorous and total nitrogen targets are not to be applied as absolutely no exeedence values should occur since occasional minor exeedences of these values do not equate to conditions necessary to cause nuisance algae growth.

4.3.2 Supplemental Indicators for Nutrients

4.3.2.1 Biological Indicators

Both macroinvertebrate and diatom associations may provide supplemental indications of nutrient conditions. Biological community metrics may be presented in the impairment status section as supporting information for streams that have borderline nutrient and chlorophyll *a* concentrations but generally will not carry much weight in the decision process.

4.3.2.2 Riparian Vegetation

Field assessments conducted during 2004 field measured several conditions that are provided for supplemental indicators to address nutrient enrichment in streams in the Upper Big Hole River TPA. Understory shrub cover along green line and line transect, and corresponding measures of percent bare ground relate to nutrient conditions in the streams. These follow the thresholds prescribed to address siltation (cross reference).

Measures of riparian vegetative cover classes relate to nutrient loading in several ways. First is the role of streamside vegetation in mitigating nutrient inputs, which occurs through several mechanisms. Vegetation filters and takes up nutrients contributed from overland flow and accumulations of livestock wastes near the stream. These functions are especially important in agricultural watersheds (Lowrance et al. 1984). In addition, woody species such as willows are phreatophytes, which are deep-rooted plants that obtain water from the water table. These plants have the potential to mitigate nutrients contributed from subsurface irrigation return flows that leach nutrients from soil. Another assumption in applying these measures as supplemental indicators is that an intact, functioning riparian area suggests that livestock management practices limit accumulations of manure adjacent to the stream channel. This limits the extent to which manure is a direct source of nutrients to surface waters. The greenline and cross sectional transect riparian vegetation measures are outlined further in the sediment target section above (**Section 4.2.1**). The same threshold values for sediment will be applied for nutrient supplemental indicators.

Bare ground is typically an undesirable feature in riparian areas and often an indicator of disturbance. Livestock grazing practices have the potential to increase bare ground through vegetation removal and trampling. This has implications for nutrients as increased cover of bare ground suggests that near channel sources of sediment and nutrients are elevated due to a lack of bank protection afforded by vegetation. Moreover, high proportions of bare ground limit the filtering capacity of riparian areas that limit introduction of fine sediment and associated nutrients through surface run off. Reference reach summary statistics, which will be considered for bare ground comparisons, are provided in **Table 4-23**.

Table 4-23: Percent bare ground measured along the green line on reference reaches.

Classification	N	Minimum	Maximum	25th Percentile	Median	75th Percentile
Valley Tributaries	28	0	29	0	4	13
Low Gradient Montane Tributaries	24	0	58	2	6	19
High Gradient Montane Tributaries	Not Applicable					

4.3.2.3 Percent Shrub Cover along Line Transects

Understory shrub cover measured along line transects, established perpendicular to stream flow, provided additional information on status of riparian shrubs on assessed reaches. Line transects measure the proportion of a measuring tape intercepted by various classes of vegetative cover across the flood prone area. This differs from green line counts, which enumerates the proportion of 202 equidistant points intercepting vegetative classes at the bank line. Maintaining shrub cover along the width of the flood prone area reduces the risks for nutrient production and delivery to streams by decreasing soil erosion and increasing filtering from overland flow. Thresholds based on reference sites are provided in **Table 4-24**.

Table 4-24: Percent shrub cover measured along line transects on reference reaches.

Classification	N	Minimum	Maximum	25th Percentile	Median	75th Percentile
Valley Tributaries	35	25	95	47	64	77
Low Gradient Montane Tributaries	35	4	90	20	49	76
High Gradient Montane Tributaries	Not Applicable					

4.3.2.4 Dissolved Oxygen

Low Dissolved Oxygen (DO) often occurs in rivers, lakes and reservoirs in response to excessive nutrient loading and therefore, is an indirect indicator of potential nutrient impairment. In addition, Montana has numeric standards for dissolved oxygen associated with the aquatic life use. The Montana Water Quality Standards (17.30.623 (2)(b) require that no person may violate the numeric freshwater aquatic life dissolved oxygen standards presented in **Table 4-25** (DEQ, 2006). A table of fish spawning times and schedule for the presence of early life stages of fish that are likely to occur may be found at http://www.deq.state.mt.us/wqinfo/Standards/SpawningTimesFWP.pdf. The Montana dissolved oxygen standard is 5.0 mg/L as a 7-day minimum concentration and is proposed as an interim indicator to assess the nutrient impacts and also used directly to assess compliance with Montana's DO standards. Little to no dissolved oxygen data exist during nighttime periods, therefore this indicator will not be assessed at this time, but may be assessed during a future TMDL review.

Table 4-25: Minimum Aquatic Life Standards (Class B-1) for Dissolved Oxygen (mg/L)

Time Period	Early Life Stages	Other Life Stages
30-day average	NA	6.5
7-day average	9.5 (6.5)	NA
7-day average minimum	NA	5
1-day minimum	8.0 (5.0)	4

These are water column concentrations recommended to achieve the required intergravel DO concentrations shown in parentheses. For species that have early life stages exposed directly to the water column, the figures in parentheses apply.

4.3.2.5 Summary of Targets and Supplemental Indicators for Nutrients

Targets and supplemental indicators for nutrient enrichment involves use of multiple lines of evidence (**Table 4-26**). These include water chemistry and vegetative cover. Combined, these parameters will provide a robust understanding of the trophic status of streams in the Upper Big Hole River TPA. These targets and indicators are used collectively to determine if Montana's water quality standards pertaining to nutrient impacts are likely exceeded.

Table 4-26: Numeric targets and supplemental indicators to address nutrient enrichment in streams in the Upper Big Hole River TPA.

Parameter	Threshold	Applicable Timeframe	Rationale
InterimTargets			
Total Nitrogen	<320 µg/L	July 1-Sept 30th	Nutrient contributing to eutrophication
Total Phosphorus	<49 µg/L	July 1-Sept 30th	Nutrient contributing to eutrophication
Chlorophyll a	<150 µg/L	Year Round but typical growth occurs between July 1-Sept 30th.	Measures primary productivity of benthic algae and allows inference on nutrient loading and proliferation of undesirable aquatic life
Supplemental Indicators			
Percent Shrubs along Green Line in non conifer dominated riparian zones	25th percentile and median ≥ reference reaches statistics	July 1-Sept 30th	Vegetation functions in the filtering and uptake of nutrients
Percent Shrubs along Line Transects in non conifer dominates riparian zones	25th percentile and median ≥ reference reaches statistics	July 1-Sept 30th	Vegetation functions in the filtering and uptake of nutrients
Percent Bare Ground in non conifer dominates riparian zones	25th percentile and median ≥ reference reaches statistics	July 1-Sept 30th	Increased bare ground along the stream channel suggests sources of sediment and nutrient are elevated and filtering functions of riparian vegetation are limited

Applicable dissolved oxygen standards outlined in table 4-24

4.4 Metals

Similar to other pollutants in the Upper Big Hole River TPA, targets and supplemental indicators for metals contamination use multiple lines of evidence. These include direct measures of metals in surface waters and benthic sediment, along with biological metrics shown to be sensitive to metals pollution. These targets and supplemental indicators, combined with identification of potential sources of metals contamination, are used as a direct interpretation of Montana's numeric and narrative water quality standards.

4.4.1 Metals in Surface Waters

Because numeric standards exist for metals in surface waters, numeric targets are relatively straightforward. Targets for each metal will be set to protect human health and aquatic life. The most conservative of the available numeric standards will be used (**Table 4-27**), which will be either human health standards or chronic aquatic life standards, depending on water hardness and the metal of concern. Because the data set used for the Upper and North Fork Big Hole TPAs is somewhat limited, it is assumed that unless a sample was collected during a summer rainstorm event, the sample represents a 96 hour period and thus can be applied to any of these standards.

Table 4-27: Numeric standards for metals listed as probable causes of impairment in streams in the Upper Big Hole River TPA (Circular WQB-7 2002)

Pollutant	**Aquatic Life Standards**		**Human Health Standards**
	Acute (µg/L)	***Chronic (µg/L)***	***(µg/L)***
Cadmium	0.52 @ 25 mg/L hardness	0.97 @ 25 mg/L hardness	5
Copper	3.79 @ 25mg/L hardness	8.25 @ 25 mg/L hardness	1300
Mercury (TR)	1.7	0.91	0.05
Zinc (TR)	37 @ 25 mg/L hardness[c]	37 @ 25 mg/L hardness[c]	2,000
Lead	13.98 @ 25 mg/L hardness	0.545 @ 25 mg/L hardness	15

4.4.2 Metals in Benthic Sediments

Metals associated with benthic sediment provide another means to evaluate risks to aquatic life and coldwater fisheries. Due to their close association with the streambed, benthic organisms, including many fish species, periphyton, and macroinvertebrates, have increased potential to integrate metals from benthic sediments into their tissues. This may have a direct adverse effect on these beneficial uses and provide an avenue for accumulation of metals into the food web. Metals of concern in the Upper Big Hole River TPA (cadmium, copper, and lead) have a low to moderate bioaccumulation potential based on aquatic bioconcentration factors (EPA 1985a, EPA 1985b, EPA 1985c, cited in CDM 1994). Therefore, contamination of benthic sediments with these metals will have low to moderate effects on higher trophic levels.

Evaluation of metals concentrations in benthic sediments also has an advantage over water column measures. Metal concentrations in the water column can be highly variable with factors such as stream flow. For example, increased flows can either dilute or mobilize metals and may be difficult to sample. In contrast, metals associated with benthic sediments are less susceptible to variability in flow, although large events may scour and transport these constituents.

Unlike metals concentrations in surface water, numeric targets for metals in benthic sediments are lacking. A literature review conducted by Buchman, 1999 provides a reference for evaluating the potential effect of sediment metals by identifying concentrations with observed adverse effects on aquatic species. Targets follow a conservative approach through selection of concentrations observed at or below the threshold effect level (TEL) (**Table 4-28**). Exceeding a sediment metals target by itself may indicate that further water quality monitoring is needed. How this information is used is further discussed **Section 1.4.4**.

Table 4-28: Sediment metals targets for streams in the Upper Big Hole River TPA (modified from Buchman, 1999).

Parameter	Target
Cadmium	≤0.6 mg/kg
Copper	≤36 mg/kg
Mercury	≤0.174 mg/kg
Lead	≤35 mg/kg
Zinc	≤123 mg/kg

4.4.3 Biological Indicators of Metals Contamination

Several metrics calculated from macroinvertebrate and periphyton proportional counts are sensitive to metals loading and provide targets and indicators of the influence of metals on aquatic life (**Table 4-29**). In addition, there should be no toxic risk at any level of the food chain associated with the water body if metals originate from aquatic habitats. The DEQ has employed some of these for several years, and others are under development. The percent of abnormal cells metric is a measure of the proportion of diatom frustules showing abnormalities in their shape or striae (the distinctive lines of pores allowing identification of diatom taxa). Heavy metals contamination, especially in poorly buffered waters, can result in deformation of these features. Similarly, the metals tolerance index, a diatom metric under development, is similar to the metals tolerance index developed for macroinvertebrates. Dr. Loren Bahls of Hannaea is working on calibrating this metric for use in Montana streams, and it may be available in the near future.

A metals tolerance index was constructed to assess metal contamination impacts on the macroinvertebrate community in Silver Bow Creek. This metric is used along with other metrics to indicate a potential impact to macroinvertebrate communities. This indicator should only be used with other biological indicators of metal contamination because of its uncertainty.

Table 4-29: Numeric supplemental indicators.

Parameter	Target	Description	Citation
Percent abnormal cells (diatoms)	<3%	Proportion of frustules showing deformities, which are often an indicator of metals contamination	McFarland et al. 1997, Bahls 1993
Metals sources	If no human caused metals sources are present but metals are above standards, site specific metals standards may be pursued. Significant human caused sources need to be present for TMDL completion.		
Bioaccumulation	Bioaccumulation poses no risk at all levels of food chain.		

4.4.4 Summary of the Decision Process Used to Determine if Metals TMDL are Necessary

The existence of human caused metals sources will be used as a supplemental indicator. The process chart identified in **Figure 4-1** assumes that human caused sources have been identified. **Figure 4-1** identifies the decision process used to determine if metals are impacting uses in the Upper Big Hole TPA. If water quality data exceed water column metal standards, a TMDL for the specific metal will be written. Where limited water quality samples do not exceed standards, but a sediment metal concentration is above a guidance level, biological responses are considered. If there is a toxicological response in a biological community and a high sediment metal concentration, the Department will provide a follow up water column monitoring strategy that could lead to a TMDL. If the water column chemistry (both high and low flow conditions) and biological results (both periphyton and macroinvertebrate) are not over the threshold, then it can be concluded that it is not needed.

There are a few exceptions to the general decision process. The first is where sediment chemistry metals are greater than published guidance values and upstream human caused metals sources indicate the possibility of metals conditions exceeding targets further upstream in the watershed. Under this scenario, a follow up monitoring plan will be provided. The amount of additional sampling needed in this circumstance will be based on the individual situation.

The second exception is when the metal has low toxic effects on aquatic life, but a high bioconcentration factor that is likely to influence human health through fish consumption, as is the case with mercury. In this case, high concentrations of mercury found in sediment without a toxic effect is sufficient information to trigger TMDL formation, or at least further mercury monitoring actions. This is especially true if fish tissue analysis data is available and indicates bioconcentrating effects.

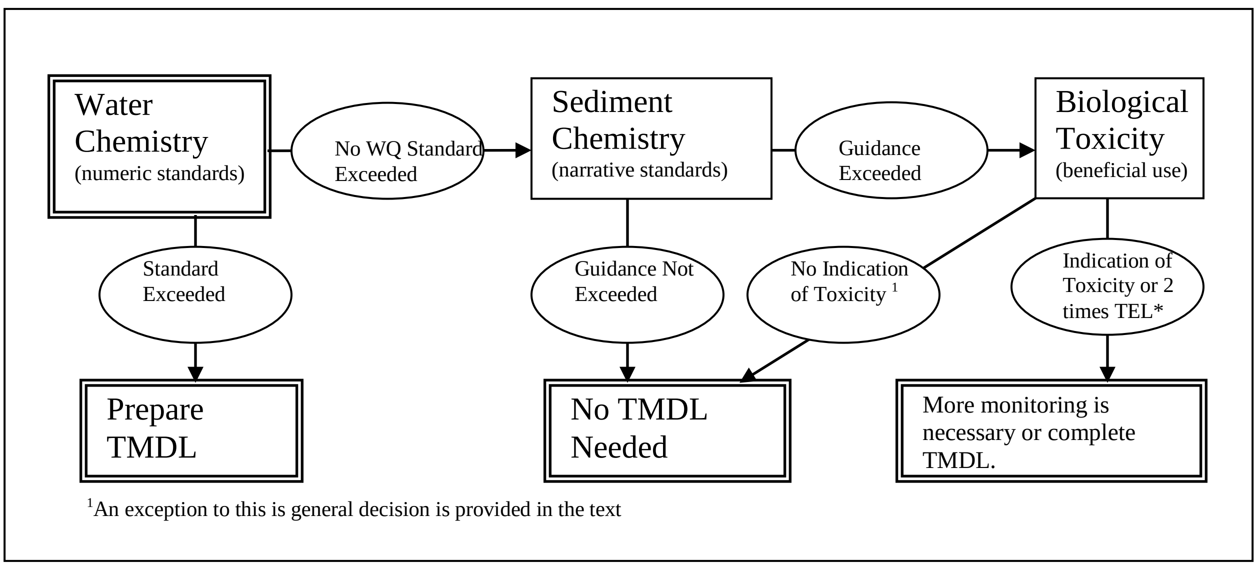

Figure 4-1: Decision Process to Determine if a Specific Metal is Impacting a Use for Upper/NF Big Hole TPAs.
*NOAA SQIRTS freshwater threshold effect level.

4.5 Miscellaneous Supplemental Indicators

Other data that pertains to beneficial uses, pollutant sources, or watershed conditions may be presented in the Existing Conditions and Data Summary section. Some of these data include differing measures of chemistry, biology, or physical measurements not specifically explained as targets and supplemental indicators. The information provided by the other measures will support overall decisions, but will not be used for TMDL targets.

Ongoing monitoring efforts in the Upper Big Hole River TPA will provide additional indicators useful in evaluating the biological, chemical, and physical integrity of streams and response to restoration activities. Fish population assessments conducted by FWP and USFS will provide valuable information on coldwater fisheries, a key beneficial use in the Upper Big Hole River TPA. Information from these efforts will be incorporated into future TMDL planning because targets are not static and may be updated based on more robust scientific understanding from future studies. MFWP and USFWS conservation goals for grayling restoration may be useful in future TMDL planning efforts and, through future implementation and study efforts, may have measurable change based on other parameters not mentioned in this document. Future TMDL reviews should consider other available, relevant, environmental measures along with the targets and supplemental indicators provided in this document.

SECTION 5.0
EXISTING CONDITIONS SUMMARY

The following sections provide a summary of available data and a comparison to water quality targets for streams identified on Montana's list of impaired waters. Although placement onto the 303(d) List indicates water quality is likely impaired, a comparison of water quality targets to existing data provides a more robust link of a specific pollutant to an impacted use and the need for TMDL development or follow-up monitoring. This review of data usually provides a more robust data set than those used for Montana's 2006 list of impaired waters. Target comparisons also establish a starting point from which to measure future water quality restoration success. This review does not take the place of the 303(d) List of sufficient and credible data reviews or beneficial use determinations.

5.1 Upper Big Hole River

This segment of Big Hole River originates south of Jackson, Montana in the Beaverhead Mountains and flows northward ending at its confluence with Pintlar Creek (**Appendix K**, **Map 1**). Tributaries flow from the Beaverhead, Pioneer and Pintler mountain ranges. The major tributaries include the North Fork Big Hole River, Warm Spring, Steel, Swamp, Governor, Big Lake, and Rock Creeks. Pine forests dominate upper elevations of the watershed. The Big Hole Valley is a broad, low gradient broad valley dominated by hay and cattle production.

Montana's 2006 integrated water quality report indicates that aquatic life, coldwater fishery, and contact recreation are partially supported in the upper segment of the Big Hole River. Potential causes of impairment are identified as alteration instream-side or littoral vegetative covers, low flow alterations and temperature. The major watershed sources identified during the TMDL source assessment are associated with transportation and agriculture.

5.1.1 Temperature

Thermal alterations on the mainstem of the Big Hole River, primarily in the form of elevated summer temperatures, present a significant constraint on the biological and physical integrity of this stream. The alteration in this thermal regime is of considerable importance due to the role of the Big Hole River in supporting the last fluvial population of Arctic grayling in the lower 48 states (Section 2). Evidence supporting this 303(d) listing, and therefore the need for a TMDL to address temperature, comes from a variety of sources and data types.

The water quality targets presented relate to riparian vegetation conditions that provide shading, stream channel conditions that promote instream thermal inertia, and thermal inputs such as irrigation return flow. Increasing instream flow by way of irrigation water saving management activities will provide thermal inertia to lessen daily temperature fluctuations. The combined suite of targets would meet Montana's water quality temperature standard if achieved. The water quality temperature standard is also provided as a target but can be difficult to assess. Temperature modeling scenarios are provided for each of the temperature influencing factors which are provided as targets. Results from the modeling scenarios provide a sensitivity analysis indicating the degree of influence each target can have on temperature conditions in the Big Hole River.

5.1.1.1 Canopy Density and Understory Shrub Cover along Streambanks

Canopy density over the stream due to riparian vegetation was measured on a number of reaches on the upper Big Hole River. This effort compared canopy density and understory shrub cover among least-impacted and impacted reaches. Statistically significant differences between reference and impacted reaches existed in the amount of overhanging riparian vegetation and shrub cover along the streambank. Impacted field assessed reaches consistently failed to meet numeric targets for canopy density, and shrub cover developed from the reference reaches (**Table 5-1**). Comparison of temperature modeling results using reference and impacted canopy density results also indicates that human influences to stream-side shade are influencing stream temperatures to a level that exceeds the temperature standard.

Only a portion of the upper Big Hole River could be assessed by field measures. Aerial photo reviews were used to extrapolate to areas that were not assessed in the field. Assessment of aerial imagery during TMDL development indicated that removal of riparian understory shrub cover has reduced stream shading over significant portions of the stream channel. Almost the entire upper Big Hole River has the potential for riparian shrubs. An aerial photo assessment indicates that approximately 25 percent of the mainstem had dense, 30 percent had moderate, and 45 percent had low density streamside shrub cover. Historic aerial photo comparisons and fence line contrasts indicate almost all of the areas of low density shrub cover are human influenced. A significant portion of the river has reduced riparian canopy cover.

5.1.1.2 Stream Channel Geometry

High width-to-depth ratios were found when comparing impacted reaches to reference reaches (**Table 5-1**). The monitoring results indicate that in most areas assessed by the aerial photo assessment with “low riparian shrub cover” have higher width-to-depth ratios. The over widened channels allow larger daily water temperature fluctuations and provide fewer deep coldwater refugia for aquatic species. A shallow and wide stream provides a large area for heat transfer during warm weather. Assuming consistent streamside canopy, a stream with a higher width-to depth ratio has reduced shading when compared to a narrower, deeper channel. Temperature modeling indicated that human caused influences to channel geometry increase maximum daily stream temperatures.

The TMDL project aerial photo analysis and subsequent field monitoring indicated that reference areas with higher riparian shrub cover were also more likely to have a low gradient, braided stream channel which promotes higher effective shade given the same vegetation height along streambanks. Many impacted areas of the upper Big Hole River are changing to a less stable Rosgen C type channel. A number of small channels have greater potential for shade from riparian vegetation than one larger channel.

5.1.1.3 Stream Flow

Stream flow is used as a supplemental indicator to be used in combination with other targets. Examination of hydrographic data showed depleted stream flows resulting from irrigation withdrawals in the basin. Reduced flow volume has less thermal inertia and is therefore more sensitive to solar inputs. Application of a supplemental indicator for flow provides additional evidence supporting the listing of the Big Hole River for temperature. Examination of stream flow at the Wisdom Bridge gage station for the past three years indicates stream flow frequently dropped below 60 cfs throughout the irrigation season (**Figure 5-1**). Stream flow was often below the fishery minimum survival flow of 20 cfs. Calculation of the frequency of flows below the target for the period of record at this gauging station indicates that these reduced stream flows occur during both dry and wet years and are not attributable solely to the recent drought conditions (**Figure 5-2**).

Meeting the CCAA and FWP instream flow targets may not always be possible while considering Montana’s water laws and varying weather conditions. An alternative approach to meeting instream flows will be to apply all reasonable irrigation water management practices in the watershed that will increase instream flows without divesting, impairing or diminishing any State recognized water right. Significant increases instream flow can be accomplished by local irrigation water savings efforts which employ water saving engineering and management practices along with water leasing or donation for instream use. Some irrigation water management practices are being used in specific areas. The alternative to meeting the stream flow targets will be to apply **all** reasonable land, soil and water conservation practices that apply to the irrigation systems in the upper Big Hole watershed. This should include an irrigation water management study to determine where the irrigation systems should be upgraded to save water without severely affecting summer groundwater return flow to the stream network. All reasonable and appropriate irrigation water management activates should be utilized which will save water for instream use. These practices may include, but are not limited to:

- Irrigation scheduling between irrigators
- Ditch lining and maintenance
- Field leveling
- Gated pipe
- Knowing water needs of the crop and soil capacity to store water
- Soil moisture monitoring
- Controlling field runoff
- Drilling wells for stock instead of stock watering diversions
- Diverting water only when needed for intended use
- Irrigation structure upgrades (for more efficient water management) and maintenance
- Coordination between water users
- Other reasonable management practices

Another target relating to stream flow and irrigation water management will be to reduce warm water irrigation return flow to the upper Big Hole River and tributaries. Although no warm surface water returns were found during the TMDL assessment, it is likely that they exist. Many of these sources are transient and hard to assess in a scientific study. Irrigation water management activities that save water would also address this source.

A holistic water balance for the irrigation and stream network could not be assessed during the TMDL project because of the hydrologic complexity of this area. This effort should occur in the future and also consider water temperature of any irrigation returns that are found. The target pertaining to warm water irrigation returns will be a 65 percent reduction in overall inflow.

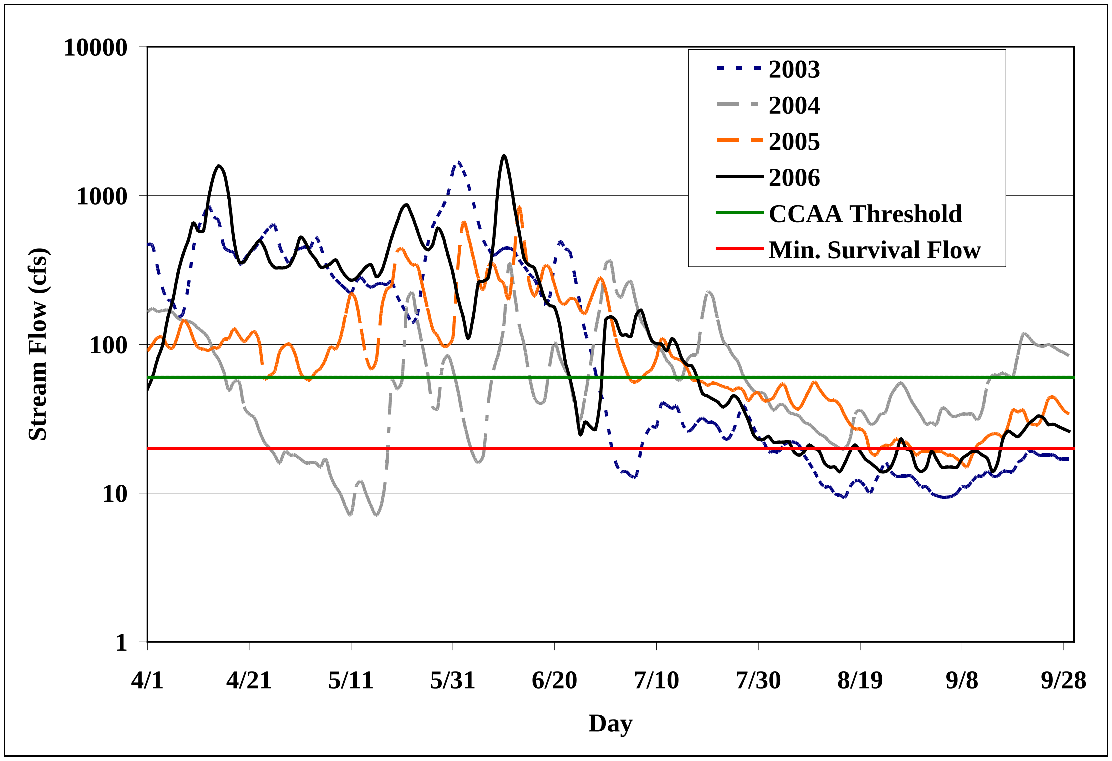

Figure 5-1: Stream flow measured on the Big Hole River at the Wisdom Bridge (USGS Gage 06024450)

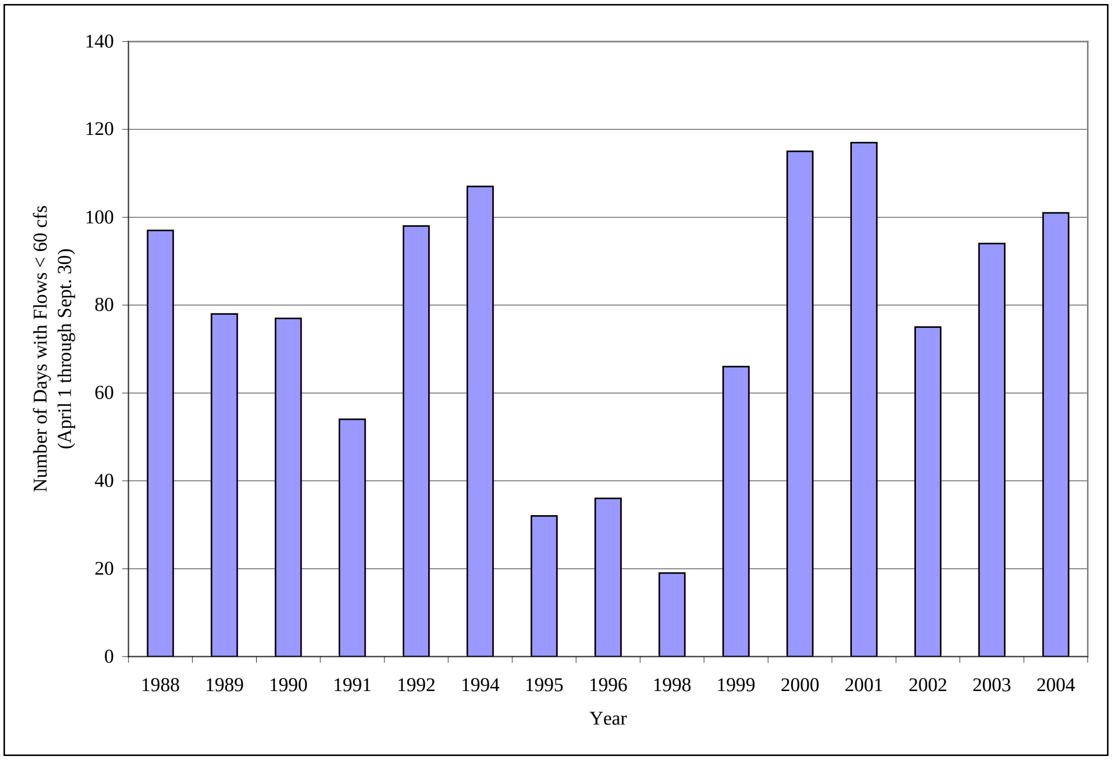

Figure 5-2: Number of days each year stream flow at Wisdom Bridge fell below 60 cfs

5.1.1.4. Temperature Data, Thermal Influences, and Link to an Impacted Use

An example is provided to link temperature conditions to shade, stream flow and stream channel conditions. A temperature monitoring site on reach BH26 represents one of the worst-case scenarios in terms of temperature due to the overly wide and shallow channel cross-section, low shrub cover, and the number of irrigation diversions upstream of this site. Maximum daily temperatures exceeded the 7-day sliding average of daily maximum temperatures known to limit fish in the same cold water class as arctic grayling (≤15 °C or 59 °F) throughout July and August. Moreover, these temperatures often approached the critical thermal maximum for Arctic grayling on several occasions. This temperature regime impacts cold stenotherms such as Arctic grayling.

Data from thermographs installed at the upper and lower ends reach BH26 indicate substantial thermal loading between the thermographs (**Figure 5-3**). The tendency for the downstream site to have markedly greater maximum daily temperatures accentuates the potential for these overly wide reaches with greatly reduced shrub cover to accrue heat during daylight hours. Additionally, the downstream site exhibits more rapid changes in temperature on both heating and cooling cycles, attributable to lower upstream canopy density, lower stream flows and higher width-to-depth ratios.

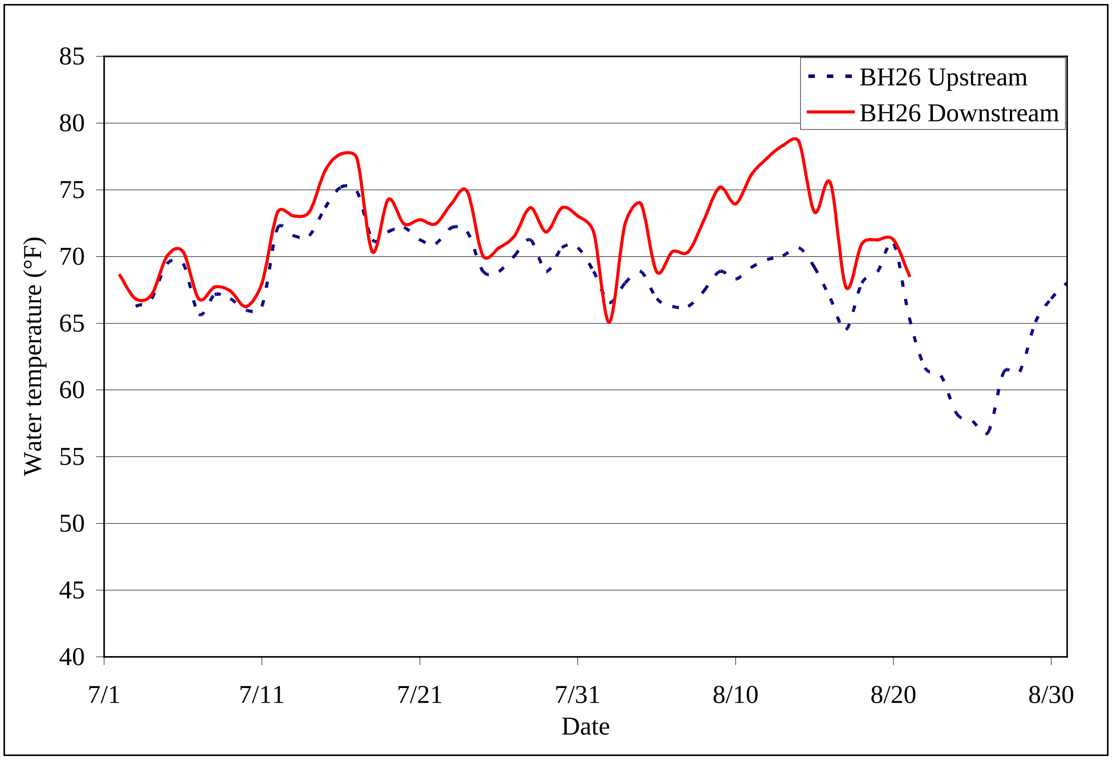

Figure 5-3: Temperatures measured using thermographs at the upstream and downstream boundaries of reach BH26 on the Big Hole River in 2004.

Examination of longitudinal trends in a sliding 7-day average maximum daily temperature target indicates temperatures exceeded a threshold likely to affect grayling over the entire length of the upper Big Hole River. Of the 13 thermographs installed in 2004, all registered temperatures in excess of 59 °F between June 30 and September 23, 2004. A tendency for the upstream stations to have fewer occurrences than downstream stations was apparent and may be due to groundwater influences along with human caused factors. Finally, an important consideration is climate during the period of record. The 2004 summer monitoring season was cooler and wetter than average, implying thermal conditions are warmer during hotter and drier years than 2004.

5.1.1.5 Temperature Modeling and Interpreting Montana’s Water Quality Temperature Standard

The SSTEMP (stream segment temperature model) was used for the upper Big Hole River to assess how stream temperature would fluctuate in response to increased stream shading, decreased channel width-to-depth ratio and an increase instream flow due to improved irrigation efficiency. Because of the complexity of the braided stream channel and the irrigation system network of the upper Big Hole Watershed, a full system assessment could not be completed. Alternatively, several segments with less complex hydrology were assessed with the SSTEMP model. Several reaches were modeled and compared to reference conditions during modeling scenarios.

Model results show that the increasing flow rate has minimal effect on lowering mean daily temperatures, but a significant effect on lowering daily maximum temperatures. Model runs simulating improved vegetation predict decreases in both mean and max outflow temperatures. Reducing stream channel width-to-depth ratios reduced maximum daily outflow temperatures but had little affect on the mean daily temperature. A more detailed description of the modeling is provided in Appendix B.

Land uses affecting stream side shade are also a significant factor influencing temperature. Modeling an increase instream shading to reference levels resulted in a simulated average daily decrease instream temperature from 0.5 to 1.5 ºF along one of the modeled segments depending on stream flow conditions, while another segment had a slightly smaller decrease. Modeling indicates that this source alone is likely impacting temperature to a level that exceeds Montana's temperature standards. The modeling only assessed a few segments of the stream, but cumulative shade affects along the whole upper Big Hole River and its tributaries are a very significant influence on stream temperatures. An increase instream shading could be achieved through reasonable management changes and restoration projects designed to increase riparian vegetation.

Modeling scenarios that increased flows also contributed to reduced stream temperature. These scenarios simulate less irrigation water withdraw associated with reasonable irrigation water management. These scenarios estimated that daily maximum water temperatures drop from 0.5-1 ºF for every 10 cfs increase instream flow in the range of 10 to 80 cfs. Saving 10 cfs in the Upper Big Hole Watershed via irrigation water management activities is likely achievable with a local, voluntary effort that would not affect water rights if designed properly. This indicates reasonable irrigation water management activities could reduce stream temperatures significantly. Likely, water quality temperature standards are exceeded from this source alone. Until a basin wide, detailed irrigation system assessment is completed, irrigation water savings are only speculated by extrapolating results from other nearby studies.

Many areas of the upper Big Hole River are over widened due to lack of riparian species with deep binding root mass. Modeling scenarios indicated that the over widened stream channels contribute to increased heating and cooling rates. Widened channels produce more extreme high and low temperatures, but only slightly influence average daily temperatures. Modeling results indicate that over widened stream channels on the upper Big Hole River likely contribute to temperature standard exceedences during warm summer afternoons.

A modeling scenario combined increased shading, increased flow and narrower channels together. This scenario estimated stream temperature decrease of about 1.5-1.75 ºF along one segment of the stream, depending on flow conditions. This assumes that 10-15 cfs can be applied to instream flow from irrigation water management. The modeling only assessed a few segments of the stream, but cumulative affects from stream flow, shading and channel width along the whole upper Big Hole River and its tributaries are a very significant influence on stream temperatures. When considered together, changes to these three physical factors influence stream temperature to a degree that exceeds water quality temperature standards. Details of methods used for modeling and model results are included in Appendix B.

5.1.1.6 Summary of Temperature Conditions

Comparisons of available data to targets provide substantial evidence in that the upper segment of the Big Hole River is in need of a temperature TMDL (**Table 5-1**). All the targets are exceeded. Shrub density, shading, stream flow and channel geometry in impacted reaches deviated considerably from the targets. Modeling results suggest that these physical disturbances have a substantial effect on stream temperatures.

Table 5-1: Upper Big Hole River Temperature Targets and Existing Conditions

Criteria	Rationale	Current Status
Maximum allowable increase over naturally occurring temperature	Montana's standard: For waters classified as A-1 or B-1, a 1ºF maximum increase above naturally occurring water temperature is allowed within the range of 32ºF to 66ºF; within the naturally occurring range of 66ºF to 66.5ºF, no discharge is allowed which will cause the water temperature to exceed 67ºF; and where the naturally occurring water temperature is 66.5ºF or greater, the maximum allowable increase in water temperature is 0.5ºF.	Modeling indicates that water temperature is increased by more than 0.5ºF when water temperatures are above 66.5ºF. Riparian vegetation reductions, over widened stream channels and irrigation inefficiencies contribute to heating.
Meet the Temperature Target Above or Meet All of the Surrogate Targets Below.		
Canopy Density Over the Big Hole River	The 25th percentile of all measures that represent the continuum of conditions along the segment ≥ 31% and the median ≥ 49%. No stream length greater than 1000 yards can fall below half of these values (25th percentile of 15% and median of 25%) because of localized heating concerns.	About half the assessed reaches fall below target values. Aerial photo assessment indicates significant stream lengths are likely below target values..
Canopy Density Over the Tributaries in the Valley	The 25th percentile of all measures that represent the continuum of conditions along the segment ≥ 36% and the median ≥ 64%. No stream length greater than 1000 yards can fall below half of these values (25th percentile of 18% and median of 32%) because of localized heating concerns.	Many tributaries are not meeting targets.
Irrigation Return Flows	Sixty five percent reduction in all irrigation return flow water that is warmer than stream water.	None were noted during TMDL monitoring, but are likely present. A thermal infrared assessment and water balance study would be useful for further assessing this target.
Point Sources	No permitted point sources.	
Supplemental Indicator (temperature dissipative capacity)		
Stream Flow	Apply irrigation water (IWM) savings from all reasonable irrigation efficiency projects to instream use during warmest months (July.-Sept).	Modeling indicates the daily maximum stream temperatures in August could be cooled by 0.5-1 ºF for every 10 cfs of instream applied IWM efficiency savings during low flow conditions. Reasonable IWM efficiency savings are unknown but expected to be at least 10 cfs based on other regional IWM study results.

5.1.2 Sediment

Sediment in the form of siltation was among listed probable causes of impairment on the 1996 303(d) List. Subsequent lists identified pollution such as riparian habitat alteration and flow alteration as causes of impairment. Nevertheless, associated forms of pollution such as "other habitat alterations" may influence delivery, in-stream sorting and transport of sediment in the Big Hole River. Therefore, this TMDL planning effort examined the information relating to sediment pollution, including physical measures that relate to sediment delivery, channel stability, sediment deposition and sediment transport.

Initial TMDL assessment of aerial photos described several indications that sediment delivery, channel stability, sediment deposition and sediment transport may be impacted in the upper Big Hole River. Information compiled in this process suggested that bank erosion associated with livestock grazing practices and willow removal was likely a significant in-channel source of sediment (OEA 1994). In addition, a reduction instreamside willows appeared to result in formation of an overly wide and shallow channel. This channel morphology can lead to accumulations of fine sediment on the streambed because of reduced sediment transport efficiencies and may produce a stream channel with fewer or less quality pools filled by larger sediment class sizes.

Comparisons among a time series of aerial photos indicate that land use practices adjacent to the stream were increasing the delivery of sediment from in channel sources. A reduction in shrub cover corresponded to significant lateral migration of streambanks. Between 1955 and 1996, an 81 percent reduction in riparian shrub cover occurred in areas with historic photos available. Associated with this vegetation removal was lateral bank migration of up to 94 feet on bend ways. Channel adjustments of this extent result in introduction of many tons of sediment into the system and increase channel width, which decreases the capacity of the channel to transport sediment.

Field surveys during 2004 provided several lines of evidence to evaluate the sources of sediment and the extent to which accumulations of sediment impact beneficial uses (**Appendix C**). These included a survey of eroding banks within assessed reaches, assessment of channel characteristics, riparian vegetation conditions, pebble counts, and percent fine grids measured with a viewing bucket.

Overall, pebble counts suggested relatively low proportions of fine sediment in riffles of the upper Big Hole River, all measures were less than 11 percent. Overall, fine sediment in riffles appears to be at levels that are below target levels. Sampling with the viewing bucket in pool tails indicated a tendency for two reference reaches to have low proportions of surface fines, while impacted reaches were more variable (**Table 5-2**). In light of the uncertainty associated with these data, a supportable conclusion is that the upper two reference reaches appear to have low proportions of surface fines in pool tails and in riffles, while accumulations of fine sediment may be a constraint on fish spawning habitat on lower reaches of the upper segment of the Big Hole River near Wisdom.

Pool frequency (number of bankfull widths between pools) is higher (a lower statistic) at most sites monitored in the upper half of the Big Hole River segment. Pool frequency is lower (higher statistic) in the lower half of the segment. This roughly corresponds with shifts in documented channel geometry due to past and current riparian vegetation conditions. Pools have been filled with course sized sediment originating from streambanks.

Width-to-depth ratios measured on reference and impacted reaches of the Big Hole River provide evidence that channel alterations may reduce sediment transport and sorting efficiency. Impacted reaches were overly wide and often exceeded width-to-depth ratio targets by a considerable extent (**Appendix C**). Also, over-wide stream channels usually have less pool habitat, which is a critical habitat for fish use. Wider channels were found in areas with less shrub cover along the streambanks.

The amount of bank erosion on the upper Big Hole River is quite variable and depends mainly upon how riparian vegetation has been managed along streambanks. A number of monitoring locations have large areas of eroding bank. Much of the bank erosion is also associated with changes instream channel type. Historically, the Big Hole River in the upper valley was mostly a braided stream system with smaller, deeper channels. In many areas where the stream is no longer a braided system it now exerts more energy on unstable banks causing large shifts in the channel where shrubs lacking on streambanks.

Shrubs hold together streambanks because of their extensive root systems. Historical (1940s) and recent aerial photo comparisons indicate significant reduction in riparian greenline shrub cover. Most sites that were monitored had low shrub growth on streambanks. During the initial phases of TMDL development, aerial photo assessments indicate that low shrub cover is common along the entire segment, although some areas do contain well managed riparian areas. An aerial photo review of 1996 to 2005 indicates that bank retreat rates are much higher in single channel areas with low riparian shrub growth when compared to areas having higher greenline shrub density within this segment of the Big Hole River.

5.1.2.1 Summary of Sediment Conditions

Targets and supplemental indicators associated with sediment loading and transport suggested increased sediment inputs from near channel sources combined with impacts to sediment transport because of stream channel change. Although results are less certain about the instream sediment measures, fine sediment measures indicate that coarse and fine sediment is impacting the fishery by depositing in pool and pool tail areas. It appears that fine sediment in riffles is not likely to affect aquatic insect food sources for the fishery. Pool frequency was very low in many of the impacted reaches suggesting sediment from eroding banks contributes to pool filling and over-widened stream channels. Pool filling by coarse and fine sediment likely impacts the fishery use by limiting adult use of pools for security and by impacting fish spawning areas.

5.1.3 Biological Indicators

A macroinvertebrate community assessment along the upper Big Hole River indicates areas with healthy communities and areas of impacted communities. The variability is likely due to the diverse conditions of riparian vegetation and channel conditions within this segment of river.

5.1.4 Big Hole River Existing Condition Conclusions

In conclusion, available data for the Big Hole River support pursuing a temperature TMDL. Irrigation withdrawals, channel widening, and a reduction in riparian shrub cover result in temperatures that negatively affect grayling and modeling indicates that Montana's temperature standards are exceeded during hot summer days. These temperatures are likely presenting sublethal and potentially lethal stress on Arctic grayling. Riparian vegetation alteration is clearly linked to excessive stream instability and associated excessive bank erosion. This leads to very high sediment loading and an associated loss of pools linked to the excess sediment within the stream (i.e. the sediment load is contributing to the "filling" of pool habitat). Pools are essential for secure fish holding cover and specific areas of pools are also essential for fish spawning habitat. The TMDL will address the considerable linkage between the sediment loading and riparian vegetation alteration along with other sources of sediment in the watershed.

Table 5-2: Summary of sediment targets and existing conditions for the Big Hole River.

Parameter	Target or SI	Reach/Site Name	Value	Threshold	Threshold Met?
Pebble Counts (≤6mm in riffles)	Target	BH09	0%	≤ 10	Y
		BH16	8%		Y
		BH18	0%		Y
		BH19	7%		Y
		BH22	9%		Y
		BH26	3%		Y
		BH26R	8%		Y
		BH28	**11%**		~
		BHO8	6%		Y
Pebble Counts (≤2mm in riffles)	Target	BH09	0%	≤ 10	Y
		BH16	1%		Y
		BH18	0%		Y
		BH19	2%		Y
		BH22	8%		Y
		BH26	0%		Y
		BH26R	3%		Y
		BH28	8%		Y
		BHO8	1%		Y

Table 5-2: Summary of sediment targets and existing conditions for the Big Hole River.

Parameter	**Target or SI**	**Reach/Site Name**	**Value**	**Threshold**	**Threshold Met?**
Fines Grid (≤6mm pool tailout)	Target	BH09	4	Median ≤ 22	Y
		BH18	11		Y
		BH28	**50**		**N**
		BH08	6		Y
		BH16	15		Y
		BH19	16		Y
		BH22	**57**		**N**
		BH26	12		Y
		BH26R	**100**		**N**
Width-to-depth ratio	Target	BH09	75^{th} = 25 M = 22	75th percentile ≤ 26 Median ≤ 22	Y
		BH18	75^{th} = **33** M = **27**		**N**
		BH28	75^{th} = 21 M = 22		Y
		BH08	75^{th} = **55** M = **51**		**N**
		BH16	75^{th} = **34** M = **28**		**N**
		BH19	75^{th} = **55** M = **44**		**N**
		BH22	75^{th} = **35** M = **34**		**N**
		BH26	75^{th} = **68** M = **59**		**N**
		BH26R	75^{th} = **58** M = **56**		**N**
Understory shrub cover along the green line	Target	BH09	25^{th} = 70 M =75	25th percentile ≥ 31 Median ≥ 50	Y
		BH18	25^{th} = 36 M =50		Y
		BH28	25^{th} = **19** M =**24**		**N**
		BH08	25^{th} = **21** M =**27**		**N**
		BH16	25^{th} = **35** M =**24**		**N**
		BH19	25^{th} = **18** M =**14**		**N**
		BH22	25^{th} = **8** M = **9**		**N**
		BH26	25^{th} = **0** M = **0**		**N**
		BH26R	25^{th} = **0** M = **2**		**N**

Table 5-2: Summary of sediment targets and existing conditions for the Big Hole River.

Parameter	Target or SI	Reach/Site Name	Value	Threshold	Threshold Met?
Pool Frequency (# of Bankfull Widths between pools)	Target	BH09	4.7	Median ≤ 4.7	Y
		BH08	3.7		**N**
		BH28	3.0		Y
		BH18	**5.6**		Y
		BH16	**28**		**N**
		BH19	**77**		**N**
		BH22	4.8		**N**
		BH26	**78.0**		**N**
		BH26R	**83**		**N**
Macroinvertebrates	SI	**Four out of seven samples indicate significant shift in aquatic insect community**			
Human Sources Present	SI	**Yes**			
Eroding banks (ft^2)	SI	BH09	**493**	≤ 406	**N**
		BH18	0		Y
		BH28	128		Y
		BH08	**942**		**N**
		BH16	249		Y
		BH19	**593**		**N**
		BH22	0		Y
		BH26	281		Y
		BH26R	**620**		**N**

5.2 Doolittle Creek

Doolittle Creek is a tributary of the Big Hole River which flows from the Pioneer Mountains northwest to the confluence with the Big Hole River (**Appendix K**, **Map 1**). Montana's 2006 Integrated Water Quality Report indicates that a number of beneficial uses are only partially supported in Doolittle Creek. Potential causes of impairment are identified as alteration instream-side or littoral vegetative covers, low flow alterations and sedimentation/siltation. The major watershed sources identified during the TMDL source assessment are associated with transportation and agriculture.

USFS information indicated numerous potential sources of sediment loading to surface waters from land use activities. Nevertheless, an important consideration in interpreting USFS reports is that the provided descriptions of conditions are prior to implementation of BMPs and major restoration activities in the drainage and are probably an unreliable indicator of current conditions. Assessments of aerial imagery by Confluence (2003) suggested that land use activities may be reducing willow cover in the lower portions of the stream and that irrigation withdrawals decreased stream power to the extent that channel definition was lost in these reaches. These initial analyses supported the 303(d) List status of Doolittle Creek.

The USFS provided updated reviews on the conditions and management activities instreams on their lands, including Doolittle Creek during the TMDL process (Wisdom Ranger District, USFS, unpublished reports). This narrative reiterated likely increases in sediment loading in the

Doolittle Creek watershed from a number of activities on USFS lands, including poorly designed roads, timber harvest, and livestock grazing through the 1990s. In response to the observed and modeled increases in sediment loading from land uses on the Forest Service lands, the USFS implemented BMPs and restoration activities to decrease production and delivery of sediment to streams. Grazing management changes included decreasing stocking rates and duration of grazing, improvements to off-channel watering systems, and implementation of grazing and riparian standards within the allotments.

5.2.1 Sediment

The USFS conducted an initial analysis of suspended sediment and discharge data collected from the mid-1980s through the early 1990s that suggested that livestock grazing practices contributed suspended sediment that exceeded the narrative standards for A-1 waters (USFS, unpublished report). This data won't be provided in detail since it does not represent current conditions very well.

Beneficial use support determinations for sediment, either in suspension or on the streambed, need to consider implementation of BMPs since the 1990s. These have occurred on both public lands in the headwaters and private lands in the valley portions of the watershed. Improvements to roads and changes in grazing management strategies have likely improved conditions in this stream with regard to sediment pollution. The following is a discussion of restoration activities as well as a description of existing conditions.

In response to concerns regarding sediment pollution in the Doolittle Creek watershed, the USFS made several changes in management during the 1990s. This included a considerable investment in improving roads to reduce sediment delivery to streams supporting genetically pure westslope cutthroat trout. Road improvements totaling $270,000 included surfacing roads adjacent to streams, armoring of erosion sites, installing rock lining in ditches, moving culverts, installation of drivable dips to channel water, and armoring cattle crossings to reduce bank and channel disturbance from hoof shear. Monitoring of these improvements by the USFS indicate these improvements have been successful in reducing sediment loading from roads.

Most available information focuses on USFS holdings; data on the privately owned reaches of Doolittle Creek are relatively scarce. USFS narratives provided qualitative descriptions of land use and history of these sites, which landowners along Doolittle Creek confirmed or revised. The two properties at the lower end of Doolittle Creek have been under conservation easement since the 1970s.

The lowest reach on Doolittle Creek (DC04) rated as having moderate to sparse riparian shrub cover as observed from aerial photos, but field observers in 2004 noted that although the riparian corridor was relatively narrow, a buffer of willows occurred along almost the entire reach during aerial photo reconnaissance for site selection. Reaches upstream on the monitoring location appeared to have healthy stands of shrubs.

Sediment TMDL monitoring during 2004 provided an opportunity to evaluate the response of riparian and instream conditions to management changes over the past decade on USFS lands and provided a ground truth observations from aerial imagery (Confluence et al. 2003). TMDL monitoring occurred on reach DC03, just upstream of the reach discussed above. Results from sediment and riparian vegetation monitoring on Doolittle Creek indicate that a sediment TMDL is still necessary. However, an understanding of the spatial extent of these conditions needs to inform interpretation of these results. This reach represented the worst-case scenario for Doolittle Creek but was a relatively short reach (only about 1/5 the total stream length), and field notes suggest that conditions were improving due to a recent change in grazing management strategies. Other considerations include the geology of the basin, which may naturally contribute more sand than other watersheds in this area.

Comparison of existing conditions to sediment targets and supplemental indicators, that indicate the need for a TMDL included an eroding bank survey, vegetation assessment along the banks, and measures of substrate fines. Compared to valley reference streams, Doolittle Creek had an elevated level of bank erosion (**Table 5-3**). Low proportions of shrub cover combined with high levels of bare ground suggesting insufficient bank protection, which increases the risk of bank erosion (**Table 5-3**). Pebble counts and percent fines grid assessments indicated relatively high levels of fine particles. In contrast, several other monitored conditions met targets. Width-to-depth ratios were low suggesting the stream may have the ability to transport fine sediment (**Table 5-3**). Instream habitat data indicated an abundance of deep pools, which implies that aggradation of sediment particles is not limiting this important habitat feature in this area.

Biological monitoring on Doolittle Creek provides a direct measure of aquatic life, a key beneficial use. Aquatic insect community were monitored at two sites during 2003. A site located near the USFS boundary met biological health metric threshold. Not enough insects could be collected at a second site near the confluence with the Big Hole River to determine the health of the macroinvertebrate community. The reason for low aquatic insect numbers at this site is unknown.

5.2.1.1 Summary of Sediment Conditions and Conclusions

Sediment loading and transport are likely affected by human influences and are contributing to increased fine sediment within the stream channel (**Table 5-3**). Targets relating to the functional attributes associated with sediment loading (vegetation measures, eroding banks) suggested potential for increased sediment inputs from near channel sources. Fine sediment has accumulated on the stream bottom and may be limiting aquatic life use. Most sediment sources are likely historic, although human influences are still present, but recently many best management practices have been implemented in this watershed. A sediment TMDL will be provided in this document and will consider the overall condition of the watershed when determining the TMDL allocations and restoration approach.

Table 5-3: Summary of sediment targets and existing conditions for Doolittle Creek.

Pollutant	Parameter	Reach Name	Target or SI	Value	Threshold	Threshold Met?
Sediment	Pebble Counts Percent fines (≤ 6 mm in riffles)	DC03	Target	**33**	≤ 22	**N**
	Pebble Counts Percent fines (≤ 2 mm in riffles)	DC03	Target	**23**	≤ 18	**N**
	Percent Fines Grid (≤6mm pool tailout)	DC03	Target	M = 55 25^{th} = 38	Median ≤ 80 25^{th} percentile ≤27	Y
	Pool frequency	DC03	Target	6	≤ 8	Y
	Width-to-depth ratio	DC03	Target	75^{th} = 12 M = 8	75th percentile ≤ 20 Median ≤ 14	Y
	Understory shrubs along greenline	DC03	Target	**25th = 6** **M =9**	25th percentile ≥ 32 Median ≥ 58	**N**
	Eroding banks (ft^2)	DC03	SI	**1094**	≤ 212	**N**
	Macroinvertebrates	One site met biological threshold. Too few insects collected at another site to determine community health.				
	Human Sources Present	Yes, but mostly historic. Many BMPs are in place.				

5.3 Fox Creek

Fox Creek is a small stream in the southern end of the upper Big Hole River planning area (**Appendix K**, **Map 1**). Its headwaters begin in the Big Hole Divide between Dillon and Jackson on USFS lands. After leaving the forest, it flows through private lands for about ¾ of its length before its confluence with Governor Creek. Prior 303(d) lists included Fox Creek as partially supporting coldwater fisheries and aquatic life due to habitat alterations and siltation. This project assessed sediment/siltation conditions because of the prior listings. The 2006 303(d) List identifies phosphorus as likely limiting aquatic life and fishery use but was not assessed during this basin wide TMDL project because it is a relatively new listing.

5.3.1 Sediment

Initially, aerial photo assessments and USFS narratives were available for review. During TMDL development the USFS provided detailed stream narratives describing land uses and stream conditions. In addition, recent investigations have shed light on the current condition of Fox Creek with respect to sediment and related pollution. In 2003, the DEQ monitoring personnel conducted assessments to meet sufficient credible data requirements for Fox Creek. This included biological assessments, water chemistry, and application of a qualitative, rapid habitat assessment questionnaire. In 2004, field TMDL investigations included a significant reconnaissance effort and subsequent assessment of in-stream sediment conditions, stream channel characteristics, bank erosion assessments, and riparian vegetation quantifications.

Stream narratives provided by the US Forest Service (Wisdom Ranger District, unpublished reports) provide information on land use, fisheries, and stream health for the upper reaches of

Fox Creek. This basin is part of the Fox Creek grazing allotment with livestock occupying sagebrush flats and meadows adjacent to streams. One third of a mile of gravel and native surface roads per square mile occur in the basin, which is quite low. In addition, three road crossings exist in the 12 square mile watershed. No timber harvest has occurred in the Fox Creek watershed.

Fisheries investigations in the Fox Creek drainage include fish sampling on the mainstem and the North Fork of Fox Creek in the late 1980s and late 1990s. Eastern brook trout were the most abundant fish followed by westslope cutthroat trout. Westslope cutthroat trout presumably occur in the South Fork of Fox Creek although no fisheries data were available for this stream.

USFS hydrologists assessed the North Fork in 1999, which is not part of the listed segment but could contribute pollutants. The assessed reached rated as an overly wide C4 channel without an apparent trend in condition. Livestock trampling was the identified cause of changes in physical habitat on the North Fork, including formation of an overly wide and shallow channel. Also, aerial photo review indicates few mature shrubs in upper Fox Creek which may be an indication of poor grazing management. This degradation was apparently a recent development as a 1986 memo considered habitat conditions in the North Fork of Fox Creek to be 92 percent of optimum. Pebble counts conducted on the North Fork of Fox Creek indicate low surface fines.

During the field reconnaissance investigations, observers viewed both private holdings and USFS lands along Fox Creek. Field notes from this effort indicate most areas had intact riparian status and function and no indication of impairment from human activities. Dense growth of willows and sedges dominated many riparian areas and no indications of erosion were apparent. Relatively recent efforts in rehabilitating Fox Creek were apparent by presence of dead willow stakes in banks. Representatives of the landowner confirmed ongoing efforts to improve riparian health and fish habitat on private holdings through grazing management, maintenance of instream flows, and channel restoration.

Width-to-depth ratios were similar to or less than reference reaches (**Table 5-4**). Bank erosion was rare with only one of the two assessed reaches having eroding banks and this was less than the average of valley reference reaches (**Table 5-4**). Proportions of fine sediment from pebble counts were low, although fines measured with the viewing bucket were elevated at one site and the number of pools at this site were lower than expected (**Table 5-4**). The conditions at this site were likely influenced by irrigation structures and past placer mining and may not be due to increased sediment yield. All other measures met sediment targets and supplemental indicator thresholds. Although the aerial photo assessment indicated areas of the headwaters where riparian filtering and bank stability function may be impacted by grazing.

Macroinvertebrate community assessment results indicate the presence of a diverse community, likely due to a complex habitat and sediment regime which promotes a healthy macroinvertebrate population. MFISH reports that Fox Creek has populations of brook trout, mottled sculpin and westslope cutthroat trout. No information is reported for fish species within the North and South Fork of Fox Creek and Sawmill Creek.

Table 5-4: Summary of targets and existing conditions for Fox Creek.

Pollutant	Parameter	Reach Name	Target or SI	Value	Threshold	Threshold Met?
Sediment	Pebble Count Percent fines (≤ 6 mm in riffles)	FC02	Target	6	≤ 22	Y
		FC03		1		Y
	Pebble Count Percent fines (≤ 2 mm in riffles)	FC02	Target	5	≤ 18	Y
		FC03		1		Y
	Percent Fines grid (≤ 6 mm pool tailout)	FC02	Target	M = 62 **25th = 59**	Median ≤ 80 25th percentile ≤ 27	**N**
		FC03		M = 36 25^{th} = 16		Y
	Pool frequency	FC02	Target	**24**	≤ 8	**N**
		FC03		8		Y
	Width-to-depth ratio	FC02	Target	75^{th} = 10 M = 8	75th percentile ≤ 20 Median ≤ 14	Y
		FC03		75^{th} = 16 M = 14		Y
	Understory shrubs along greenline	FC02	Target	25^{th} = 32 M = 45	25th percentile ≥ 32 M ≥ 58	≥
		FC03		25^{th} = 65 M = 69		Y
	Eroding bank (ft^2)	FC02	SI	NA	≤ 212	
		FC03		35		Y
	Macroinvertebrates	A diverse aquatic invertebrate community exists.				
	Human Sources Present	Many reasonable land soil and water conservation practices are in place for transportation system and grazing system, the two main human activities in the watershed. Some improvements in grazing system can be reasonably expected.				

NA = no visually eroding banks

5.3.2 Summary of Sediment Conditions and Conclusions

Almost all of the targets and indicators are met except for percent fines in pool tail out areas and pool frequencies at site FC02. These target exeedence conditions may be due to historic channel alterations yet human caused sediment sources do exist in the watershed and may influence sediment conditions. Almost all reasonable land, soil and water conservation practices that affect sediment production and transport are in place except for a potentially small area in the North Fork and other headwater areas. Therefore, a sediment TMDL for Fox Creek is pursued at this time and should be achievable via implementing riparian grazing management systems which reduce bank erosion and increase streamside shrub growth in specific areas of the watershed.

5.4 Francis Creek

Francis Creek drains from the east side of basin flowing to the northwest before its confluence with Steel Creek. The headwaters originate in USFS lands, but most of its length flows through state or private land. Francis Creek was identified in the 2006 303(d) List with sedimentation/siltation, alteration instreamside vegetation, nitrogen and phosphorus as the probable causes of impairment to fish and aquatic life.

5.4.1 Sediment

Stream narratives prepared by the USFS (Wisdom Ranger District, Beaverhead National Forest, unpublished reports) provide evidence of conditions likely to increase sediment loading to Francis Creek. The forested portions of the Francis Creek drainage have a significant amount of roads with 23 percent rating as low road density, 33 percent with moderate road density, and 23 percent with high density of roads. Road crossings provide a potential route of delivery of sediment to streams with 6 road crossings on perennial streams, and 26 road crossings on intermittent streams. In addition, timber sale monitoring for Francis Creek identified culvert failures as a source of sediment to surface waters in the drainage.

Livestock grazing practices also probably contribute fine sediment to Francis Creek (Wisdom Ranger District, Beaverhead National Forest, unpublished reports). Grazing allotments account for nearly all the USFS holdings in the drainage. Stream surveys in 1993 reported heavy trampling by livestock in Sheep Creek, a tributary of Francis Creek, and along the mainstem of Francis Creek. In sections of Francis Creek and Sheep Creek, the channels have down cut substantially. As a result, the stream can no longer access its floodplain to dissipate energy during high flows, which further increases the erosive power and contributes more sediment. In Sheep Creek, a shift in the median diameter (D_{50}) of streambed particles from 180 mm to 31 mm between stations above and below livestock caused bank damage suggested significant loading of fine sediment from this source.

Aerial photo assessments identified several conditions consistent with prior sediment 303(d) listing in Francis Creek. Notably, riparian shrub cover observable from aerial imagery was sparse for the non-forested portions of the stream. In addition, dewatering was apparently preventing transport of sediment resulting in a lack of channel definition. Field observations during TMDL sediment surveys in 2004 support inclusion of sediment as a probable cause of impairment for Frances Creek. Field notes corroborate a lack of channel definition and describe stagnant pools with accumulations of manure. Note that these descriptions are also suggestive of nutrient sources.

In general, sediment and stream channel surveys results support the need to complete a sediment TMDL for Francis Creek. Width-to-depth ratios were similar to or more than reference reaches (**Table 5-5**). There was no bank erosion in the assessed reach because of it's boggy nature and ill defined stream channel. Although willows or other riparian shrubs were lacking, herbaceous cover was high. The boggy nature of the ill-defined channel resulted in low frequency of pools and the pools present were shallow. Percent fines grids in pool tails sampled with the viewing bucket indicated relatively high levels of fine sediment averaging 82 percent of grid cross-sections. Pebble counts also indicate high levels of fine sediment.

The aquatic insect community metrics scored below their assigned thresholds indicating an impacted biological condition. Francis Creek has the following fish populations: Arctic grayling, brook trout, burbot, longnose sucker, mottled sculpin, mountain whitefish and white sucker (MFISH). Tributaries of Francis Creek are either fishless or there is no available fish information.

5.4.2 Nutrients

Very limited nutrient sampling has occurred on Francis Creek. Based on this information, it appears phosphorus levels are extremely high (**Table 5-5**). TMDL sediment monitoring results provide additional support for completing nutrient TMDLs for Francis Creek. Livestock grazing practices had eliminated riparian shrubs along most of this stream (**Table 5-5**). The reduced riparian vegetative cover relates to nutrient pollution because riparian shrubs and grasses filter runoff and uptake nutrients from groundwater derived from agricultural sources of nutrient.

5.4.3 Summary of Sediment and Nutrient Conditions and Conclusions

Sediment and nutrient TMDLs will be completed for Francis Creek. Sediment is accumulating in riffles and pools which likely affect fish spawning success and aquatic insect communities. Concentrations of nutrients in grab samples exceeded numeric targets and nutrient tolerant organisms dominated diatom and macroinvertebrate associations. Several observers noted accumulations of manure adjacent to the stream channel as a probable source of nutrient loading. Moreover, the functional attributes of nutrient uptake and conversion by riparian shrubs is impacted due to their absence. Although the information is limited, it identifies sources and nutrient impacts. Therefore, development of nutrient TMDLs for Francis Creek is warranted.

Table 5-5: Summary of targets and existing conditions for Francis Creek.

Pollutant	Parameter	Reach Name	Target or SI	Value	Threshold	Threshold Met?
Sediment	Pebble Count Percent fines (≤ 6 mm in riffles)	FR01	Target	**18**	≤ 13	**N**
	Pebble Count Percent fines (≤ 2 mm in riffles)	FR01	Target	**16**	≤ 13	**N**
	Percent Fines grid (≤ 6 mm pool tailout)	FR01	Target	**M = 84** **25th = 76**	Median ≤ 51 25th percentile ≤ 42	**N**
	Pool frequency	FR01	Target	**12**	≤ 6	**N**
	Width-to-depth ratio	FR01	Target	75th = 12 **M = 11**	75th percentile ≤ 13 Median ≤ 10	~
	Understory shrubs along greenline (%)	FR01	Target	**25th = 0** **M = 0**	25th percentile ≥ 36 M ≥ 41	**N**
	Eroding bank (ft^2)	FR01	SI	NA	≤ 113	Y
	Macroinvertebrates	The aquatic insect community metrics do not meet threshold.				
	Human Sources Present	Grazing, hay, and transportation sources present.				
Nutrients	Total Nitrogen	7/24/2003 FR01	Target	167	< 320 ug/L	Y
		7/24/2003 FR03		157		Y
	Total Phosphorous	7/24/2003 FR01	Target	**287**	<49 ug/L	**N**
		7/24/2003 FR03		**223**		**N**
	Chlorophyll *a*	7/24/2003 FR03	Target	27.9*	<150 mg/m^2	Y
	Understory shrubs along greenline (%)	FR01	SI	**25th = 0** **M = 0**	25th percentile ≥ 36 M ≥ 41	**N**
	Shrubs along transect (%)	FR01	SI	**25th = 0** **M = 0**	25th percentile ≥ 64 Median ≥ 47	**N**
	Bare ground along transect (%)	FR01	SI	M = 0	Median ~ 0	Y
	Macroinvertebrates	The aquatic insect community metrics do not meet threshold.				
	Human Sources	Grazing and hay production sources are present.				

***estimated due to laboratory quality assurance**
NA = no visually eroding banks

5.5 Governor Creek

Governor Creek, a tributary of the Big Hole River, lies in the southern end of the upper Big Hole River planning area (**Appendix K**, **Map 1**). Its headwaters originate in the Beaverhead Mountains and flow northward to its confluence with the Big Hole River near Jackson, Montana. About 2 miles of the length of Governor Creek flow through mountainous topography on USFS holdings. The remaining 20 miles occupy a rangeland environment on private land. Probable causes of impairment in Governor Creek have included sediment on past lists and now include related pollution such as dewatering, alteration instream side vegetation, and physical substrate habitat alterations on the 2006 list. In addition, Governor Creek is listed for copper on the 2006 303(d) List.

5.5.1 Sediment

Descriptive narratives written by the USFS (Wisdom Ranger District, Beaverhead National Forest, unpublished documents) provide information on land use and stream status on US Forest Service holdings in the headwaters of Governor Creek. Roads may be a factor in the basin with an average road density of 1.2 miles of road/mile^2 area. Road density varies across the drainage with 20 percent considered low road density, 54 percent being moderate, and 26 percent being high road density.

Livestock grazing is another activity on public lands in the headwaters. Habitat and hydrologic assessments in the mid 1980s and late 1990s indicated livestock grazing on USFS holdings resulted in alterations to the physical integrity of this stream. Near the Forest boundary, this resulted in loss of undercut banks and formation of an overly wide channel. Surveyed cross sections indicate relatively narrow channel in monitoring reaches on Governor Creek.

Pebble counts conducted at two locations on USFS holdings suggest that land use activities were resulting in accumulations of harmful levels of fine sediment on the streambed. The downstream sampling site, had high levels of particles less than 1 mm in diameter. Particles in this size class are detrimental to coldwater fisheries and associated aquatic life by clogging interstices in the streambed. This limits habitat available to benthos and decreases survival to emergence for salmonid fry by smothering eggs (Kondolf 2000).

The aerial assessment conducted for TMDL reconnaissance efforts showed evidence of riparian clearing and associated bank line erosion in numerous reaches. Nevertheless, two reaches identified as having potential as reference reaches based on observed channel and riparian conditions were eliminated from this consideration following field reconnaissance. Although the riparian corridor was relatively intact, reconnaissance investigations in these potential reference reaches found substantial channel instability.

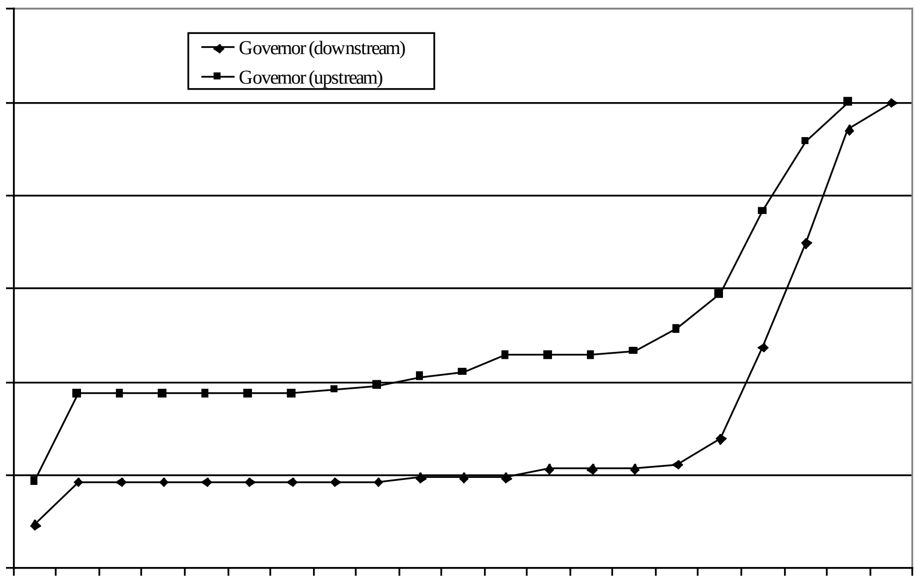

Figure 5-4: Cumulative percent frequency of particles sampled in pebble counts on the Governor Creek in 1999 collected by USFS.

Field observations during TMDL monitoring surveys provide insight into site conditions on Governor Creek. Assessed reaches were typically overly wide with evidence of trampling and vegetation removal. Field observers also noted accumulations of fines on the streambed due to the reduced sediment transport abilities of the overly wide channel. Conditions observed were usually attributed to lack of healthy riparian vegetation.

Data collection supporting the sediment TMDL also indicate that sediment conditions are effected by lack of riparian vegetation in Governor Creek (**Table 5-6**). Compared to the valley reference reaches, reaches on Governor Creek were overly wide and shallow and entrenchment ratios suggested downcutting, or channel degradation. In addition, reduced shrub cover and high proportions of bare ground occurred on all three assessed reaches on Governor Creek.

The bank erosion survey results indicated accelerated bank erosion in assessed reaches of Governor Creek compared to reference reaches (**Table 5-6**). One reach in particular had over 800 square feet of eroding bank in the highly erodible category. In comparison, reference reaches typically had less than 212 square feet of eroding bank in this category.
The area of eroding banks exceeded targets substantially on two of the three assessed reaches. Moreover, measures of riparian cover classes indicated reaches had reduced shrub cover and elevated levels of bare ground along the banks; these conditions reduce filtering capacity and decrease bank protection. None of the three assessed reaches met the target for width-to-depth depth ratio indicating an overly wide channel which likely reduces sediment transport capabilities.

Results of pebble counts indicated low proportions of fines; however, percent fines measured with the viewing bucket in pool tail out areas were high compared to reference reaches. Measures of substrate composition were contradictory with low percent fines measured in pebble counts and elevated percent fines measured with the fines grid on 2 of the 3 reaches (**Table 5-6**).

No aquatic insect community assessments are available from Governor Creek. Governor Creek has known populations of brook trout, burbot, longnose dace, longnose sucker, mottled sculpin, mountain whitefish, rainbow trout, westslope cutthroat trout and white suckers (MFISH). Although it is thought that grayling may occur rarely in Governor Creek, they have not been found in this part of the watershed by the FWP grayling monitoring efforts in over a decade (Lamoth and Petersen 2007). The culverts at the Skinner Meadows Road crossing have the potential to become a seasonal velocity barrier to grayling migration. The energy focused by these structures coupled with changes to the riparian vegetation downstream is causing alterations to the local stream channel morphology and habitat quality (Lamoth and Petersen 2007).

5.5.2 Copper

Governor Creek is listed for likely impairment on the 2006 303(d) List due to elevated copper concentrations in several grab samples collected in the early 1980s. A significant amount of uncertainty remained on the appropriateness of this listing for several reasons. First, detection limits from older analyses were often too high for reliable application of the numeric standards and data reliability at levels near the standards is questionable. This uncertainty results in an increased probability of false violations when using data from this vintage. In addition, data currency, or the extent to which these data represented current conditions, was unknown. Finally, a lack of land use activities likely to increase loading of metals suggested these results were anomalous or unrelated to actual contamination of surface waters by copper (**Appendix K**, **Map 3**).

Because of the uncertainty surrounding the potential for copper to impair beneficial use support in Governor Creek, DEQ undertook additional sampling of water and sediment chemistry during 2004. Copper was undetected in water samples. Copper associated with benthic sediment was present in the concentration of 14.2 mg/kg. This falls below the lowest evaluated effect level for benthic invertebrates (NOAA SQIRTs) indicating low risk to benthic organisms in contact with these substrates. Together, these results indicate copper likely does not present a constraint to beneficial uses in Governor Creek. Because of the uncertainty of data from the 1980s and results of the 2004 monitoring, a copper TMDL will not be completed at this time.

5.5.3 Summary of Sediment and Copper Conditions and Conclusions

Comparison of conditions in and along Governor Creek to sediment targets and supplemental indicators provides support for pursuing sediment TMDL development (**Table 5-6**). Sediment accumulation in pools and poor instream habitat conditions likely affect aquatic insect and fish communities. Channel geometry is over wide and likely impacts sediment transport.

Copper was below detection limits in recent water sampling and less than concentrations with known effects for aquatic organisms in benthic sediments. Human caused copper sources are not present in the watershed. Therefore, a copper TMDL will not be pursued.

Table 5-6: Summary of sediment and metals targets and existing conditions for Governor Creek.

Pollutant	Parameter	Reach Name	Target or SI	Value/ Score	Threshold	Threshold Met?
Sediment	Pebble Count Percent fines (≤ 6 mm in riffles)	GC04	Target	9	≤ 22	Y
		GC06		2		Y
		GC11		0		Y
	Pebble Count Percent fines (≤ 2 mm in riffles)	GC04	Target	8	≤ 18	Y
		GC06		2		Y
		GC11		0		Y
	Percent Fines grid (≤ 6 mm pool tailout)	GC04	Target	**M = 95** **25^{th} = 92**	Median ≤ 80 25th percentile ≤ 27	**N**
		GC06		M = 80 **25th = 76**		**N**
		GC11		M = 5 25^{th} = 4		Y
	Pool frequency	GC04	Target	**10**	≤ 8	**N**
		GC06		**10**		**N**
		GC11		7		Y
	Width-to-depth ratio	GC04	Target	**75th = 35** **M = 18**	75th percentile ≤ 20 Median ≤ 14	**N**
		GC06		**75th = 33** M = 15		**N**
		GC11		75^{th} = 21 **M = 20**		**N**
	Understory shrubs along greenline	GC04	Target	**25th = 0** **M = 0**	25th percentile ≥ 32 M ≥ 58	**N**
		GC06		25^{th} = 30 **M = 33**		**N**
		GC11		**25th = 23** **M = 26**		**N**
	Eroding bank (ft^2)	GC04	SI	149	≤ 212	Y
		GC06		**350**		**N**
		GC11		**840**		**N**
	Macroinvertebrates	None Available				
	Human Sources Present	Grazing and transportation systems present.				
Copper	Copper in benthic sediments	8/24/2004 GOV01	target	14.2	< 35 mg/kg	Y
	Copper in water column	8/24/2004 GOV01	target	ND	5.2 ug/L @ 50 mg/L hardness	Y
	No known human caused copper sources.					

*ND = Non detect

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5.6 Johnson Creek

Johnson Creek lies in the northwest portion of the upper Big Hole River Valley and is a tributary of the North Fork Big Hole River. Its headwaters originate in the Anaconda Pintler Range and it flows southward approximately eleven miles to its confluence with North Fork Big Hole River. Probable causes of impairment on the 2006 303(d) List for Johnson Creek include sedimentation/siltation and several associated types of pollution including flow alterations and alterations instream side vegetation. Prior 303(d) lists have included metals listings but the TMDL project provided updated information that removed these causes of impairment from the most recent list. The 2006 list also added total kjehldahl nitrogen (TKN) to a list of potential causes of impairment in this stream. The TKN listing occurred after the TMDL project was initiated and will not be addressed at this time.

5.6.1 Sediment

Information addressing sediment as a constraint on beneficial use support comes from various sources including watershed narratives developed by the USFS, aerial photo analysis conducted during TMDL development, and TMDL field monitoring results. Narrative stream descriptions prepared by the Beaverhead National Forest provide a description of land uses and management activities in the basin. Roads and multiple use trails are a significant feature in the basin with 22 percent rating as low road density, 32 percent as moderate density, and 15 percent as high density of roads. The remaining 30 percent of the basin has no roads. Thirty-one road crossings occur in the basin on the USFS lands with all but nine crossing intermittent streams. Timber harvest is a historic activity in the watershed. Livestock grazing is another land use with 75 percent of the basin within a grazing allotment. Natural disturbance is also a feature of this sub-watershed with 27 percent of the area affected by wildfire in 2000.

Historic mining, in the form of placer mining, is another human influence with potential effect on water quality in Johnson Creek. This relates primarily to sediment pollution to the extent that channel alterations alter delivery or transport of sediment. Observers during 2004 field surveys noted evidence of placer mining and piles of waste rock on the floodplain in both of the assessed montane reaches of Johnson Creek.

The USFS conducted hydrologic evaluations in the 1980s, 1990s, and 2000s. These investigations describe Rosgen B3 channels comprising a significant portion of Johnson Creek with instream habitat provided by scours and large woody debris. Evaluations in the 1980s indicated areas where livestock management practices were incompatible with riparian health and function resulting in an overly wide channel and relatively high embeddedness. These conditions improved in subsequent decades with a narrowing of the channel and reduction of embeddedness due to implementation of grazing BMPs.

Aerial photo assessments provided several indications that human activities were likely increasing delivery of fine sediment to Johnson Creek. In the valley reaches, reductions in riparian shrub cover and extensive storage of sediment on point bars was evident in aerial images. The lowest reach on Johnson Creek showed evidence of multiple irrigation diversions.

Results of sediment TMDL monitoring in the montane portions of Johnson Creek reflected mainly natural disturbance from the Mussigbrod fire that burned much of the basin in 2000. This event drastically altered vegetation and probably contributed considerable quantities of fine sediment to the stream. For example, woody vegetation, in the form of trees or shrubs, was nearly absent from assessed reaches on Johnson Creek. In contrast to every other reach assessed in the upper Big Hole River planning area, herbaceous ground cover was the dominant vegetative feature comprising nearly 100 percent of both line transects and the green line. The proliferation of herbaceous ground cover probably reflected an early stage of succession following a catastrophic fire that burned the riparian vegetation in these areas.

Measures of substrate composition also indicated a high level of sediment with recent disturbance being a probable source of sediment loading. Field observations and pebble counts (**Table 5-7**) described elevated levels of fine sediment on the streambed. Although roads and timber harvest may have a role in long term sediment loading to Johnson Creek, inputs associated with wildfire probably dwarf these contributions in the short term.

Results from sediment TMDL monitoring in the valley portions of Johnson Creek (JC07) indicate a relatively healthy riparian corridor and stream channel, although fine sediment accumulation may impact the fishery. Width-to-depth ratios on the valley portion of Johnson Creek are equivalent to valley tributary reference reaches (**Table 5-7**). The amount of understory shrubs along the green line was similar to reference reaches (**Table 5-7**). The bank erosion survey assessments indicate existing vegetative conditions are sufficient to maintain bank stability in this reach of Johnson Creek (**Table 5-7**). Bank erosion conditions in the lower reach of Johnson Creek were similar to reference reaches. This suggests in-channel contributions of sediment in this area are not elevated above natural. In-channel measures of habitat quality were inconsistent with impacts from siltation. Pool frequency was almost equivalent compared to reference reaches (**Table 5-7**), also pool depths were similar to reference. Substrate fines in riffles were low compared to reference but the distribution of sediment in pool tailouts is elevated compared to valley reference sites.

Aquatic insects were assessed at two sites, one on the forest service and one site about a mile above the confluence with the North Fork Big Hole River. Both sites showed borderline aquatic insect community health. Johnson Creek has populations of brook trout, burbot, longnose dace, longnose sucker, mottled sculpin, mountain whitefish, sculpin, westslope cutthroat trout, white sucker and westslope cutthroat and yellowstone cutthroat hybrids (MFISH).

5.6.2 Summary of Sediment Conditions and Conclusions

Comparison of available data to targets and supplemental indicators for Johnson Creek provides mixed results. Sediment conditions for assessed reaches of Johnson Creek varied (**Table 5-7**). With regard to width-to-depth ratios, montane reaches occupied B channels, which are resilient to lateral adjustments making this parameter less applicable. However, the valley reach (JC07) approximated the target for valley tributaries. Comparisons of area of eroding banks with the supplemental indicator suggests in-channel contributions of sediment were within natural levels. Pool frequency was comparable or better than reference at all sites. Measures of substrate fines were variable with mixed results among reaches although the fire has probably influenced instream sediment conditions within the upper portion of the watershed.

Targets addressing vegetative characteristics on montane portions mainly reflected the recent wildfire that had altered vegetative cover. Shrubs and trees were largely absent leaving the riparian zone dominated with ground cover. Bare ground was another significant component of riparian cover suggesting impacted filtering of sediment and nutrients from upland sources. Nevertheless, bare ground was unattributable to human activities with no evidence of livestock use.

A detailed sediment source assessment will be pursued in Section 8 because sediment indicators imply elevated sediment conditions within the stream. Recent fire confounds the interpretation of instream monitoring results and a more detailed source assessment is needed to determine how long term sediment and water yield conditions could be affected by transportation and grazing systems within the watershed.

Table 5-7: Summary of sediment targets and existing conditions for Johnson Creek.

Pollutant	Parameter	Reach Name	Target or SI	Value	Threshold	Threshold Met?
Sediment	Pebble Count Percent fines (≤ 6 mm in riffles)	JC02	Target	21	≤ 13	**N**
		JC02R		11		Y
		JC03		44		**N**
		JC07		5	≤ 22	Y
	Pebble Count Percent fines (≤ 2 mm in riffles)	JC02	Target	13	≤ 13	Y
		JC02R		7		Y
		JC03		34		**N**
		JC07		5	≤ 18	Y
	Percent Fines grid (≤ 6 mm pool tailout)	JC02	Target	M = 64 25th = 40	Median ≤ 10 25th percentile ≤ 5	**N**
		JC02R		M = 3 25th = 2		Y
		JC03		M = 99 25th = 96		**N**
		JC07		M = 51 25th = 46	Median ≤ 80 25th percentile ≤ 27	**N**
	Pool frequency	JC02	Target	5	NA	NA
		JC02R		6		NA
		JC03		5		NA
		JC07		9	≤ 8	~
	Width-to-depth ratio	JC02	Target	75th = 18 M = 17	75th percentile ≤ 15 Median ≤ 13	**N**
		JC02R		75th = 14 M = 12		Y
		JC03		75th = 23 M = 12		**N**
		JC07		75th = 17 M = 15	75th percentile ≤ 20 Median ≤ 14	~
	Understory shrubs along greenline	JC02	Target	25th = 0 M = 0	NA	NA
		JC02R		25th = 4 M = 5		NA
		JC03		25th = 0 M = 0		NA
		JC07		25th = 51 M = 59	25th percentile ≥ 32 M ≥ 58	Y
	Eroding bank (ft2)	JC02	SI	NA	≤ 113	NA
		JC02R		NA		NA
		JC03		70		Y
		JC07		122	≤ 212	Y
	Macroinvertebrates	Two sites sampled 2004 indicate borderline aquatic community health when compared to metric thresholds.				
	Human Sources Present	Transportation and grazing sources are present. Recent fire also influences sediment yields.				

NA = no visually eroding banks

5.7 Joseph Creek

Joseph Creek is a small tributary of Trail Creek lying entirely in montane areas of the upper Big Hole River planning area on the west side of the basin. Probable causes of impairment for Joseph Creek include sedimentation/siltation, copper and lead in addition to a habitat related listing linked to sediment conditions.

5.7.1 Sediment

Information relating to sediment pollution in Joseph Creek comes from stream narratives developed by the USFS, an MDT road sanding study, aerial photo assessments, and also clean water act and TMDL sediment and habitat related monitoring. According to the USFS narratives, Highway 43 is a major influence on Joseph Creek and parallels the stream for much of its length. This includes three bridge crossings. Although this is a paved road, road traction sanding is a potential source of sediment input to this stream. Results from a MDT road sanding inventory indicate that very small portions of the creek receive road sand inputs because most of the stream length has adequately wide, low gradient, well vegetated, buffer where road sand is trapped. The reported traction sand load is likely not significant at a watershed scale although localized sections of stream do receive road sand.

Evidence from USFS narratives indicates livestock grazing was formerly a constraint on water quality; however, implementation of BMPs in the 1990s was successful in recovering channel morphology and riparian vegetation. Moreover, this resulted in a decrease in embeddedness from 40 percent to 10 percent. Evaluations of aerial photos indicated encroachment of Highway 43 resulted in the channelization of a considerable portion of Joseph Creek. Limited timber harvest was also observable in the headwaters from aerial images.

When considered all together, the TMDL sediment and streamside habitat monitoring results do not indicate that sediment standards are exceeded in Joseph Creek. Parameters specific to channel morphology and bed form indicate a narrow, deep channel with high frequency of pools that benefit fish (**Table 5-8**). Vegetation measures indicated intact function of the riparian zone with low proportions of bare ground and dense stands of willows. These functional components serve to filter sediment contributed from upland sources and protect streambanks from erosion. Furthermore, both measures of instream sediments indicated low proportions of fine sediment on streambed surfaces (**Table 5-8**). In-channel sources of sediment were lacking with eroding banks being rare on Joseph Creek.

Aquatic insect communities were assessed at two sites. Monitoring at one site did not produce the number of insects needed to assess the community, the reasoning for this is unknown. The other site failed to meet supplemental indictator thresholds but it appears that sediment and stream habitat conditions are not likely the cause. Joseph Creek has populations of brook trout, burbot and mottled sculpin (MFISH). All of the tributaries of Joseph Creek contain populations of brook trout and sometimes mottled sculpin.

5.7.2 Metals

Evidence for metals contamination in Joseph Creek comes from data collection efforts in 2001. Further monitoring was completed during 2004. Data from both years suggest metals were not a problem at the upper sampling site; however, indications of metals were pronounced at a site lower in the watershed during 2001. Both copper and lead in grab samples exceeded acute aquatic life standards in 2001 at the lower sampling site (**Table 5-8**). In 2004 copper levels found in sediment samples in the watershed were below the thresholds that are likely to cause biological response. Biological evidence for metals contamination was not pronounced.

A confounding factor in TMDL planning for metals in Joseph Creek is an apparent lack of mining activity in the watershed. Examination of four databases housing mine location data (DEQ's abandoned hard rock database, Department of State Lands abandoned mines database, the Montana Bureau of Mines and Geology abandoned and inactive mines database, and the US Geological Surveys abandoned mine database) uncovered no mining activity in the Joseph Creek watershed (**Appendix K**, **Map 3)**. Field reconnaissance did not find evidence of past or present mining activity. When inquired, the Montana Department of Transportation indicated no toxic spills along the lost trail pass transportation corridor. The absence of mining activity suggests that high levels of metals in Joseph Creek are a natural phenomenon in a mineralized basin and therefore does not require a TMDL.

Table 5-8: Summary of targets and existing conditions for sediment and metals in Joseph Creek

Pollutant	Parameter	Reach or Site Name	Target or SI	Value/ Score	Target Column	Met target?
Sediment	Pebble Count Percent fines (≤ 6 mm in riffles)	JO02	Target	15	≤ 13	~
	Pebble Count Percent fines (≤ 2 mm in riffles)	JO02	Target	8	≤ 13	Y
	Percent Fines grid (≤ 6 mm pool tailout)	JO02	Target	M = 48 25^{th} = 31	Median ≤ 50 25th percentile ≤ 42	Y
	Pool frequency	JO02	Target	4	≤ 6	Y
	Width-to-depth ratio	JO02	Target	75^{th} = 12 M = 12	75th percentile ≤ 13 Median ≤ 10	Y
	Understory shrubs along greenline	JO02	Target	25^{th} = 58 M = 59	25th percentile ≥ 36 M ≥ 41	Y
	Eroding bank (ft^2)	JO02	SI	NA	≤ 113	Y
	Human Sources Present	Transportation along with limited silviculture and grazing systems are present in the watershed.				

Table 5-8: Summary of targets and existing conditions for sediment and metals in Joseph Creek

Pollutant	Parameter	Reach or Site Name	Target or SI	Value/ Score	Target Column	Met target?
Copper	Benthic sediments	J-2 8/24/2004	target	17.1	<35 mg/kg	Y
	Water column	J-2 7/2/2001	target	**14**	Acute = 4 and Chronic = 3 ug/L @ 25 mg/L hardness	**N**
	Water column	J-2 5/24/2004	target	ND	Acute = 4 and Chronic = 3 ug/L @ 25 mg/L hardness	Y
	Water column	J-2 8/25/2004	target	ND	Acute = 5 and Chronic = 4 ug/L @ 32 mg/L hardness	Y
Lead	Benthic sediments	8/24/2004	target	9	< 35 mg/kg	Y
	Water column	J-2 7/2/01	target	**29**	Acute = 14 and Chronic = 0.5 ug/L @ 25 mg/L hardness	**N**
	Water column	J-2 5/24/04	target	ND	Acute = 19 and Chronic = 0.75ug/L @ 25 mg/L hardness	Y
	Water column	J-2 8/25/2004	target	ND	Acute = 19 and Chronic = 0.75ug/L @ 25 mg/L hardness	N
Metals Sources	No known human caused sources.					
Biology	Macroinvertebrates	Two macroinvertebrate community assessments indicate potentially impacted conditions but could be the result of other influencing factors.				

NA = no visually eroding banks

5.7.3 Summary of Sediment Conditions and Conclusions

Review of existing data confirms metals contamination; however, there are no known human caused sources. Therefore, lead and copper TMDLs will not be pursed at this time. The possibility exists that elevated metals are a natural feature in this mineralized basin. If this is the case, a TMDL is not required as the contamination is natural and not subject to clean up under the Clean Water Act.

Potential human sources of sediment loading to Joseph Creek include limited contributions from road traction sanding, grazing, and upland sources associated with timber harvest and unpaved roads. Even though limited human caused sources are present, it appears that reasonable management of the watershed results in stream conditions that are not likely to affect aquatic life. Because of this, a TMDL will not be pursued at this time.

5.8 North Fork Big Hole River

The North Fork Big Hole River begins at the confluence of Trail Creek and Ruby Creek on the west side of the upper Big Hole River basin. The stream flows to the northeast for about 15 miles before joining the Big Hole River. The 2006 303(d) List indicates probable causes of impairment for the North Fork Big Hole River as low flow alteration, alteration instream-side vegetation, and sedimentation/siltation. Credible evidence also indicates this stream may have thermal alterations as well, although this is not currently a listed probable cause of impairment.

5.8.1 Sediment

Available information includes the aerial photo assessment initial TMDL planning (Confluence 2003), temperature monitoring by Montana Fish, Wildlife & Parks, TMDL field surveys conducted in 2004, and biological assessments conducted by DEQ personnel.

Aerial photo analyses identified two primary concerns for the North Fork Big Hole River, riparian degradation and reduced stream flows (Confluence et al. 2003). Reduced shrub cover was often associated with channel migration and meander cutoffs suggesting inputs of fine sediment from channel adjustments.

Sediment TMDL field measures further supported that a sediment TMDL is needed for the North Fork Big Hole River. Compared to internal reference reaches, impacted reaches on this stream were significantly wider and shallower and showed a greater degree of entrenchment suggesting greater horizontal and vertical channel adjustments. These adjustments can produce sediment and also locally reduce the streams ability to transport sediment. Vegetative differences varied markedly between reference and impacted reaches with reference reaches having significantly greater cover of riparian shrubs and lower proportions of bare ground. Channel adjustments likely have reduced pool abundance with lower reaches having very few pools.

The amount of surface fines varied between habitats that were measured (**Table 5-9**). Pebble counts indicated low proportions of fines at all sites except at a transitional area just as the Ruby and Trail Creeks exit the mountains and form the North Fork Big Hole River. In contrast, fines measured within pool tailouts were lower at the upper reach and increased considerably downstream. In areas that riparian vegetation has been impacted, sediment levels appear to be high where fish are likely to spawn.

Bank erosion surveys provide a strong case that streamside management practices are increasing sediment loading to the North Fork Big Hole River (**Table 5-9**). Within reference reaches on the North Fork Big Hole River, eroding banks were a minor feature and comprised around 200 square feet of eroding bank. In contrast, the area of eroding banks on impacted reaches ranged between 1500 and 1800 square feet with most rating within the “high” category of erodibility. These results indicate bank erosion is a significant source of sediment within this watershed. The amount of bank erosion at all sites measured on the North Fork of the Big Hole River was directly and inversely related to the amount of riparian shrub cover. An aerial photo review indicates that the four sites measured represent the overall stream well. In general, shrub growth along the stream corridor is reduced in vigor in a downstream direction.

Pebble count and grid toss results suggest deposition of sediment likely hurts fish and aquatic life. Width-to-depth ratios on impacted reaches were elevated considerably compared to reference. Moreover, pool frequency, as expressed by average bankfull width per pool, was substantially depressed at the lowest reach (**Table 5-9**). This suggests that lateral adjustments relating to eroding banks had reduced the sediment transport capacity to the point that the stream could no longer maintain quality pool habitat in the lower reach. This represents a form of sediment pollution and is a constraint on the support of coldwater fisheries, which rely on pool habitat.

Aquatic insects were assessed at two sites (see **Table 5-9**). The aquatic insect community health was below regional reference metric thresholds at both sites. The North Fork of the Big Hole River has several species of fish, including: arctic grayling, brook trout, burbot, longnose Dace, longnose sucker, mottled sculpin, mountain whitefish and rainbow trout.

Table 5-9: Summary of sediment targets and existing conditions in North Fork Big Hole River.

Pollutant	Parameter	Reach Name	Target or SI	Value/ Score	Target Column	Met target?
Sediment	Pebble Count Percent fines (≤6mm in riffles)	NF02	Target	**16**	≤ 12	**N**
		NF06		7		Y
		NF07		8		Y
		NF11		9		Y
	Pebble Count Percent fines (≤2mm in riffles)	NF02	Target	**14**	≤ 9	**N**
		NF06		5		Y
		NF07		5		Y
		NF11		7		Y
	Percent Fines grid (≤ 6 mm pool tailout)	NF02	Target	M = 11 25^{th} = 11	Median ≤ 25 25th percentile ≤ 11	Y
		NF06		**M = 38** **25th = 38**		**N**
		NF07		**M = 39** **25th = 39**		**N**
		NF11		**M = 100** **25th = 100**		**N**
	Pool frequency	NF02	Target	5	≤ 8	Y
		NF06		8		Y
		NF07		8		Y
		NF11		**17**		**N**
	Width-to-depth ratio	NF02	Target	75^{th} = 25 M = 22	75th percentile ≤ 28 Median ≤ 24	Y
		NF06		75^{th} = 29 M = 26		~
		NF07		**75th = 44** **M = 28**		**N**
		NF11		**75th = 51** **M = 42**		**N**
	Understory shrubs along greenline	NF02	Target	25^{th} = 45 M = 51	25th percentile ≥ 36 M ≥ 43	Y
		NF06		**25th = 32** **M = 36**		**N**
		NF07		**25th = 7** **M = 12**		**N**
		NF11		**25th = 0** **M = 1**		**N**
	Eroding bank (ft^2)	NF02	SI	176	≤ 212	Y
		NF06		**224**		**N**
		NF07		**1497**		**N**
		NF11		**1827**		**N**
	Macroinvertebrates	Community metrics do not meet thresholds based upon regional reference conditions.				
	Human Sources Present	Grazing, hay production, transportation and silvicuture management systems are present. Recent fire may also influence sediment yields.				

5.8.2 Summary of Sediment Conditions and Conclusions

Comparison of conditions in and along the North Fork of the Big Hole River to sediment targets and supplemental indicators provides support for pursuing sediment TMDL development (**Table 5-9**). Sediment accumulation on the stream bed and poor instream habitat conditions likely affect aquatic insect and fish communities, especially in the lower reaches of this river. Channel geometry is over-wide and likely impacts sediment transport and in-channel sorting of sediment sizes. Human caused sediment sources are present. A sediment TMDL for the North Fork of the Big Hole River is provided in this document.

5.9 McVey Creek

McVey Creek flows to the northwest joining the Big Hole River towards the northern end of the planning area (**Appendix K**, **Map 1**). Much of this stream flows upon public lands. Its headwaters begin in Forest Service holdings and a sizeable amount of the valley portions of the stream flows through state lands. McVey Creek is listed for sedimentation/siltation and alteration instream side vegetation. Recently, McVey Creek was also listed for nitrogen and phosphorus. This TMDL document will not address the nutrient listings because these listings are very recent arrivals to Montana’s 303(d) List. Sediment related listings will be addressed in this document.

5.9.1 Sediment

Several land uses in the upper, forested portions of the watershed present potential risks for increased sediment delivery to streams. Roads are concentrated north of McVey Creek but are also present south of the creek. Road crossings on USFS land include one perennial stream crossing (native material) and five intermittent stream crossings (3 native material and 2 gravel). Current USFS land uses include recreational activities associated with an multiple-use trail system and cattle grazing. Grazing allotments exist for 7,228 USFS acres, which comprises most of the USFS land.

Notes taken during reconnaissance for the 2004 monitoring effort indicate a significant portion of the reaches on the Big Hole Valley reach (not USFS) of McVey Creek is an overgrazed E channel (Rosgen 1996) with a graminoid dominated riparian zone. Willows were absent. Eroding banks were a significant feature contributing fine sediment. The overall impression from field notes is of an overgrazed stream that would probably respond favorably to temporary rest from livestock followed by implementation of grazing BMPs.

Sediment and stream channel assessments during 2004 indicate that a sediment TMDL is necessary. This is mostly due to reductions in the cover and function of riparian vegetation. No shrubs were encountered on either the line transects or the green line survey. In addition, the assessed reach on McVey Creek had significantly greater proportions of bare ground than reference reaches.

On the other hand, despite the reduced riparian vegetation, the channel had maintained much of its integrity. Width-to-depth ratios were similar to reference and the stream rated as non-entrenched (**Table 5-10**). Despite the low width-to-depth ratio that enhances the ability of the stream to transport its sediment, sedimentation was apparent in McVey Creek by exceptionally high percent fines measured with both pebble counts and viewing bucket, and the near absence of pools (**Table 5-10**). Bank erosion was also a significant feature on McVey Creek. McVey Creek exceeded levels of bank erosion encountered on reference reaches and included nearly 900 square feet of bank within the "very high" category of erodibility. These results suggest in-channel sources of sediment are significant.

Aquatic insects were assessed at two sites. Aquatic insect community health was far below regional reference metric thresholds. Only a few aquatic insects were found at one of the sites. Brook trout and westslope cutthroat trout (MFISH) have been found in McVey Creek.

Table 5-10: Summary of sediment targets and existing conditions in McVey Creek.

Pollutant	Parameter	Reach Name	Target or SI	Value/ Score	Target Column	Met target?
Sediment	Pebble Count Percent fines (≤6mm in riffles)	MV03	Target	**67**	≤ 22	**N**
	Pebble Count Percent fines (≤2mm in riffles)	MV03	Target	**60**	≤ 18	**N**
	Percent Fines grid (≤ 6 mm pool tailout)	MV03	Target	**M = 100** **25^{th} = 100**	Median ≤ 80 25th percentile ≤ 27	**N**
	Pool frequency	MV03	Target	**71**	≤ 8	**N**
	Width-to-depth ratio	MV03	Target	75^{th} = 10 M = 10	75th percentile ≤ 20 Median ≤ 14	Y
	Understory shrubs along greenline	MV03	Target	**25th = 0** **M = 0**	25th percentile ≥ 32 M ≥ 58	**N**
	Eroding bank (ft^2)	MV03	SI	**902**	≤ 212	**N**
	Macroinvertebrates	**Community metrics do not meet thresholds based upon regional reference conditions.**				
	Human Sources Present	Grazing and transportation systems are present.				

5.9.2 Summary of Sediment Conditions and Conclusions

The available information for McVey Creek confirms the need for sediment TMDL development. Livestock grazing has reduced riparian vegetation resulting in accelerated bank erosion and a reduction in the filtering capacity of streamside vegetation. Fine sediment accumulation in pool and riffle habitat impacts the fishery and aquatic insects. Although, the lack of vertical and lateral adjustments in the channel due to vegetation removal indicates that recovery of this stream is likely with relatively simple changes instream corridor management.

5.10 Miner Creek

Miner Creek flows northeast from the west part of the basin before its confluence with the Big Hole River. Over half its length lies on USFS lands with the remainder occurring on private lands in the valley. Miner Creek appears on Montana's 303(d) List for sedimentation/siltation.

5.10.1 Sediment

Stream narratives prepared by the USFS suggest a low risk of sediment delivery from land use practices in the headwater portions of the watershed. Road density in the forested portions of the basin is low with over 90 percent of Forest Service holdings designated as inventoried roadless lands. Road crossings are limited to one crossing on a perennial stream and four on intermittent waters. Although much of the basin is in a grazing allotment, livestock use appears to have little effect on surface waters in the USFS holdings. A hydrological assessment in the mid-90s indicated a functioning stream with no indications that livestock grazing negatively affected either riparian function or channel stability (Bengeyfield 1995).

Assessment of aerial imagery for Miner Creek identified no impact in terms of riparian or geomorphic condition. Riparian vegetation consists of dense to moderate shrubs for most of the stream's length. This extent of shrub and ground cover benefited the streambanks with no eroding banks encountered in the assessed reach (**Table 5-11**). Measures of channel morphology indicate a relatively narrow, deep channel with full access to its floodplain. The riparian corridor consisted of dense stands of willows both along the green line for the entire extent of the flood prone area. Vegetative parameters met targets with dense shrub cover along the green line and line transects and no bare ground. Pool frequency and pool dimensions were similar to reference reaches (**Table 5-11**). These results indicate a relatively healthy stream corridor.

Even though much of the stream corridor appeared to have healthy riparian vegetation conditions and low levels of bank erosion, fine sediment in the stream appears higher than expected. Percent fines measured with pebble counts were slightly higher than local reference conditions but not alarmingly high. In contrast, percent fines measured with the viewing bucket were at 100 percent within the monitored reach.

Field observations of high numbers of young of the year fish provide evidence that Miner Creek provides reasonably suitable conditions for aquatic life. Similar to Little Lake Creek, Miner Creek appears to provide rearing habitat to fish in the mainstem Big Hole River. The physical setting and riparian condition probably contribute to this stream's ability to provide this vital habitat. Several fish species including arctic grayling, burbot, brook trout, longnose dace, mottled sculpin and mountain whitefish are present in Miner Creek (MFISH).

Table 5-11: Summary of sediment targets and existing conditions in Miner Creek.

Pollutant	**Parameter**	**Reach Name**	**Target or SI**	**Value/ Score**	**Target Column**	**Met target?**
Sediment	Pebble Count Percent fines (≤ 6 mm in riffles)	MC06	Target	25	≤ 22	~
	Pebble Count Percent fines (≤ 2 mm in riffles)	MC06	Target	20	≤ 18	~
	Percent Fines grid (≤ 6 mm pool tailout)	MC06	Target	**M = 100** **25^{th} = 95**	Median ≤ 80 25th percentile ≤ 27	**N**
	Pool frequency	MC06	Target	5	≤ 8	Y
	Width-to-depth ratio	MC06	Target	75^{th} = 20 M = 19	75th percentile ≤ 20 Median ≤ 14	Y
	Understory shrubs along greenline	MC06	Target	25^{th} = 47 M = 51	25th percentile ≥ 32 M ≥ 58	Y
	Eroding bank (ft^2)	MC06	SI	NA	≤ 212	
	Macroinvertebrates	Three samples do not meet supplemental indicator thresholds. The presence of Miner Lake may influence the results.				
	Human Sources Present	Limited grazing and transportation systems.				

NA = no visually eroding banks

5.10.2 Summary of Sediment Conditions and Conclusions

Although much of Miner Creek appears to have healthy riparian vegetation and stream channel conditions, fine sediment is somewhat high. The causes of the sediment conditions are not all that clear, but restoration of the limited areas with grazing or road impacts could be undertaken to address sediment conditions within the stream. A sediment TMDL for Miner Creek will be provided in **Section 8.0**, but the TMDL will contain a small sediment reduction since much of the watershed appears to be managed appropriately.

5.11 Mussigbrod Creek

Mussigbrod Creek is a tributary of the North Fork Big Hole River lying on the west side of the upper Big Hole River planning area. This stream originates in the Anaconda Pintler Range and flows for about 8 miles through a montane setting, then 5 miles through the valley until its confluence with the North Fork Big Hole River. The stream flows through Mussigbrod Lake near its headwaters. Historic 303(d) lists included Mussigbrod Creek as impaired due to flow alteration, other habitat alterations, and siltation. Current probable sources of impairment include lead, physical substrate habitat alterations, other anthropogenic substrate alterations, low flow alterations and alterations instream side vegetation. Although Mussigbrod Creek is identified on as impaired on Montana’s list of impaired waters, the upper portion of this watershed is identified as in a reference condition. This section will review sediment and associated habitat conditions and also lead conditions within the watershed.

5.11.1 Sediment

USFS narratives provide descriptions of human activities and natural disturbance in the Mussigbrod Creek watershed that relate to sediment pollution. Roads and multiple use trails parallel the stream in limited areas. Nevertheless, road density in the forested areas of the basin is low with 77 percent of USFS lands considered roadless, 17 percent with low road density, and 6 percent with moderate road density. Recreation facilitated by roads and trails, livestock grazing, and limited timber harvest are uses of the basin.

Natural factors also relate to sediment in the Mussigbrod Creek drainage. Granitics comprise 90 percent of the basin, which indicates high natural loading of sand to surface waters. Wildfire is also a considerable factor in this watershed. During the 2000 fire season, 26 percent of the basin burned. Together, wildfire and granitics are major natural sources of sediment to Mussigbrod Creek. Aerial photo analyses associated with TMDL planning efforts implicated grazing practices in the Big Hole Valley reaches of Mussigbrod Creek as potentially increasing sediment loading, most notably on the lowest 3-4 miles of the stream.

Sediment TMDL monitoring results from two sites in portions of the stream located on the North Fork Big Hole Valley bottom provided support for completing a TMDL Mussigbrod Watershed. Although measures of channel morphology indicated low width-to-depth ratios along the two impacted reaches assessed, cross sections on one reach indicated moderate entrenchment (**Table 5-12**). Together, these measures indicate that the stream is laterally stable, although isolated areas of vertical adjustments may have occurred on assessed reaches. Vegetation data for Mussigbrod Creek indicated moderate cover of riparian shrubs and low proportions of bare ground, although targets were not met (**Table 5-12**).

Pool frequency is a potential measure of sediment pollution as aggradation of large particles or infilling with fine sediment can limit this important habitat feature. Pool frequency on both reaches of Mussigbrod Creek was relatively low, although maximum pool depths were similar to reference reaches (**Table 5-12**). Eroding banks comprised relatively small proportions of assessed reaches and were similar to reference reaches. Aerial photo assessment indicates that this may not be the case between the two monitored sites.

Fine sediment measurements gave variable results for the assessed reaches of Mussigbrod Creek. The upper sight, below the USFS boundary, met all fine sediment targets. In contrast, the lower site did not meet any of the fine sediment targets, suggesting siltation is likely affecting instream beneficial uses (**Table 5-12**). Field notes describing conditions on Mussigbrod Creek provide additional insight into status of this stream. Field observers described reach MC05 as having well managed livestock grazing that was consistent with channel form and riparian function. In contrast, MC07 was described as having a greater degree of bank alteration and trailing associated with livestock use. Nevertheless, willows conferred bank stability along much of this monitored reach.

High proportions of fine sediment were measured at the lower monitored site and are likely impact instream uses. Aerial photo review indicates grazing management between the two monitored sites may have the potential to introduce sediment to the stream via bank erosion and potentially via the irrigation management system which could explain the difference between sediment conditions at the two monitored sites. A sediment TMDL will be provided for the watershed to address silation in the lower reaches of Mussigbrod Creek.

Aquatic insects were assessed at one site, and showed low aquatic insect community health when compared to metrics. Arctic grayling, brook trout, burbot, longnose dace, longnose sucker, mottled sculpin, mountain whitefish and westslope cutthroat trout have been observed in Mussigbrod Creek (MFISH).

5.11.2 Lead

Mussigbrod is listed for impairment on the 2006 303(d) List due to elevated copper concentrations in several grab samples collected in the early 1980s. A significant amount of uncertainty remained on the appropriateness of this listing for several reasons. First, detection limits from older analyses were often too high for reliable application of the numeric standards and data reliability at levels near the standards is questionable. This uncertainty results in an increased probability of false violations when using data from this vintage. In addition, data currency, or the extent to which these data represented current conditions, was unknown. The only known mining activity on Mussigbrod Creek was a placer mine on a small tributary. Although placer mining can disrupt channel morphology and sediment transport, it rarely results in contamination of surface waters with metals.

Water quality sampling in 2004 aimed to evaluate the appropriateness of this listing. Lead concentrations in surface waters were below detection limits (**Table 5-12**). Similarly, lead concentrations in benthic sediment were below concentrations known to have an adverse effect on benthic organisms (**Table 5-12**). The lack of evidence for lead contamination using credible lab methods that represent current conditions combined with the absence of a likely source of metals contamination suggests this listing may not be appropriate for Mussigbrod Creek (**Appendix K**, **Map 3**). A lead TMDL will not be pursued at this time.

Table 5-12: Sediment and lead targets and existing conditions in Mussigbrod Creek.

Pollutant	Parameter	Reach Name	Target or SI	Value/ Score	Target Column	Met target?
Sediment	Pebble Count Percent fines (≤ 6 mm in riffles)	MC05	Target	15	≤ 22	Y
		MC07		**71**		**N**
	Pebble Count Percent fines (≤ 2 mm in riffles)	MC05	Target	11	≤ 18	Y
		MC07		**54**		**N**
	Percent Fines grid (≤ 6 mm pool tailout)	MC05	Target	M = 46 25^{th} = 29	Median ≤ 80 25th percentile ≤ 27	Y
		MC07		**M = 84** **25th = 76**		**N**
	Pool frequency	MC05	Target	**22**	≤ 8	**N**
		MC07		**25**		**N**
	Width-to-depth ratio	MC05	Target	75^{th} = 12 M = 11	75th percentile ≤ 20 Median ≤ 14	Y
		MC07		75^{th} = 10 M = 9		Y
	Understory shrubs along greenline	MC05	Target	**25th = 25** **M = 46**	25th percentile ≥ 32 M ≥ 58	**N**
		MC07		25^{th} = 38 **M = 43**		**N**
	Eroding bank (ft^2)	MC05	SI	60	≤ 212	Y
		MC07		126		Y
	Macroinvertebrates	One sample indicates poor community health when compared to regional reference based thresholds.				
	Human Sources Present	Transportation and grazing systems present. Very limited silviculture activity. Recent fire also influences sediment yields.				
Lead	Benthic sediments	UBHMUSS01 8/25/2004	target	6.6	<30 mg/kg	Y
	Water Column	UBHMUSS01 5/18/2004	target	ND	Acute = 5 and Chronic = 4 ug/L @ 14 mg/L hardness	Y
	Water Column	UBHMUSS01 8/25/2004	target	ND	Acute = 5 and Chronic = 4 ug/L @ 23 mg/L hardness	Y

5.11.3 Summary of Sediment and Lead Conditions and Conclusions

Lower Mussigbrod Creek contains high levels of fine sediment. Fine sediment accumulation in pool and riffle habitat likely impact the fishery and aquatic insects. A sediment TMDL will be pursued to address fine sediment accumulation in the lower reaches of Mussigbrod Creek. Although, the lack of vertical and lateral adjustments in the channel due to vegetation impacts indicates that recovery of this stream is likely with relatively simple changes along the lower portions of this stream. Low lead concentrations in both sediment and water column samples during recent monitoring, 303(d) listing was based upon older data which lacks credibility, and lack of human caused lead sources provide the basis for not pursuing a lead TMDL at this time.

5.12 Pine Creek

Pine Creek, a tributary of Governor Creek, lies in the southern end of the upper Big Hole River planning area. Its headwaters begin in USFS holding along the Big Hole Divide. It flows for about 4 miles on USFS managed lands before entering private lands. The most recent listing includes alteration instreamside vegetation and phosphorus as potential causes of impairment. The phosphorus listing will not be addressed by this document because it only recently appeared after this project began. The habitat listings will be addressed in terms of sediment and habitat together.

5.12.1 Sediment

Assessment of aerial imagery identified reaches with potential impacts from livestock grazing or other alterations in the valley reaches of Pine Creek. Riparian vegetation rated as sparse along most of the stream. In addition, numerous diversions and other alterations to the stream and floodplain associated with flood irrigation occurred in this stream.

Sediment TMDL monitoring and associated field notes on private reaches of Pine Creek suggest a stream with impacted riparian vegetation but intact channel dimensions. Compared to reference reaches, the assessed reach on Pine Creek had low width-to-depth ratios and good access to its floodplain (**Table 5-13**). This reach had a low area of eroding banks compared to reference tributaries. Yet, shrub cover was low compared to reference reaches and bare ground comprised a relatively large proportion of line transects. Finally, measures of pool frequency and quality were reduced compared to reference and high levels of fine sediment were measured in pool tailout areas (**Table 5-13**).

Aquatic insect community health was assessed at a site near the USFS boundary and at a site near the confluence with Andrus Creek. The upper site approximated regional expectations of a healthy aquatic insect community but the lower site indicates an impacted community. According to MFISH, no fish surveys have been conducted on this tributary.

Table 5-13: Sediment targets and existing conditions in Pine Creek.

Pollutant	Parameter	Reach Name	Target or SI	Value/ Score	Target Column	Met target?
Sediment	Pebble Count Percent fines (≤ 6 mm in riffles)	PN03	Target	13	≤ 22	Y
	Pebble Count Percent fines (≤ 2 mm in riffles)	PN03	Target	12	≤ 18	Y
	Percent Fines grid (≤ 6 mm pool tailout)	PN03	Target	**M = 89** **25th = 85**	Median ≤ 80 25th percentile ≤ 27	**N**
	Pool frequency	PN03	Target	**17**	≤ 8	**N**
	Width-to-depth ratio	PN03	Target	75th = 13 M = 12	75th percentile ≤ 20 Median ≤ 14	Y
	Understory shrubs along greenline	PN03	Target	**25th = 28** **M = 36**	25th percentile ≥ 32 M ≥ 58	**N**
	Eroding bank (ft^2)	PN03	SI	59	≤ 212	Y
	Macroinvertebrates	Site near USFS border indicates a relatively healthy community compared to reference based metrics. Site near mouth indicates an impacted aquatic insect community.				
	Human Sources Present	Grazing and limited transportation systems are present.				

5.12.2 Summary of Sediment Conditions and Conclusions

Although stream channel geometry and bank erosion are not severely impacted, available information for Pine Creek suggests livestock grazing practices are likely producing fine sediment accumulations in pools. Sediment levels are above reference conditions and thresholds that are likely to impact aquatic life and fish spawning. A sediment TMDL will be pursued.

5.13 Pintlar Creek

Pintlar Creek lies on the northwest side of the upper Big Hole Valley and the watershed represents the northwest boundary of the upper/North Fork Big Hole River planning area. Its headwaters lie in the Pintler Anaconda Range and it flows to the southeast to its confluence with the Big Hole River. Pintlar Creek is identified on the state's 303(d) List as limited by temperature, stream flow and physical substrate habitat alterations as the probable causes of impairment to aquatic life and fishery uses. Temperature and sediment related TMDL monitoring occurred in Pintlar Creek during 2004. Because of complications in determining if thermal conditions caused by human activities are within the allowable state standards, a temperature TMDL will not be completed at this time. Further temperature and stream flow monitoring and modeling will be needed to determine if existing conditions meet or exceed Montana's temperature standard. Existing sediment and habitat related conditions will be reviewed.

5.13.1 Sediment

A number of information sources provided information relevant to characterizing sediment conditions within Pintlar Creek. These include stream measurements and associated descriptions developed by the USFS, the TMDL aerial photo analysis, and TMDL monitoring. Information from the USFS describes severe damage from livestock for Pintler Meadows in the mid 1980s. Assessments that are more recent place this portion of Pintlar Creek in the category as “functioning at risk” with a downward trend. Channel widening and a lack of sinuosity were among concerns listed by the USFS, who stated this reach had not seemed to recover from historic grazing practices. Nevertheless, these conditions were relegated to Pintler Meadows, which has less than 1 mile of channel. The rest of the stream rated as properly functioning. Reexamination of aerial imagery confirms the impacted nature of the Pintler Meadows portion of Pintlar Creek. No shrubs were apparent from aerial photos and areas of channel instability were observable.

Evaluations of aerial imagery in the valley portions of Pintlar Creek indicate varied conditions with the most severely degraded reaches comprising a relatively small proportion of the stream (Confluence et al. 2003). These included fence line effects where differences in grazing management practices resulted in abrupt changes in riparian vegetation density and channel sinuosity. Nevertheless, the greatest proportion of Pintlar Creek had moderate shrub cover and relatively high sinuosity. Other features evident in aerial imagery were irrigation diversions that began near the USFS boundary.

Sediment TMDL monitoring results indicated intact riparian condition and channel morphology at sites that represent much of the valley portions of Pintlar Creek. Width-to-depth ratios were low and similar to reference reaches (**Table 5-14**). In addition, the stream had good access to its floodplain as expressed by high entrenchment ratios. Riparian shrub cover was dense and typically greater than reference. Field reconnaissance of the lowest portion of Pintlar Creek (reach PC06) indicates riparian and channel conditions similar to PC04.

Evidence that bank erosion was contributing excess sediment to Pintlar Creek was equivocal. On the assessed reach, measures of eroding banks varied between quality assurance replicates with one group finding little evidence of eroding banks and the other finding area of eroding banks elevated compared to reference reaches. In addition, measures of substrate composition indicated low to moderate proportions of fine sediment. Both pebble counts and percent fines grids showed proportions of fine sediment on the streambed were approximately the same as reference reaches except for when comparing the lowest quartile of data.

Field reconnaissance, sediment monitoring data and aerial photo analyses are used to estimate existing conditions. Approximately 1/4 mile of channel has markedly reduced riparian vegetation due to grazing practices. Field reconnaissance of the 1/4 mile of stream with reduced riparian cover in the valley portion of stream found no evidence of bank erosion. Sediment, produced via bank erosion in Pintler Meadows, likely becomes trapped in Pintlar Lake and is effectively removed from the system. Therefore, given the low proportion of degraded riparian area, riparian habitat alterations are unlikely contributors of excess sediment to Pintlar Creek.

5.13.2 Summary of Sediment Conditions and Conclusions

Review of existing information on Pintlar Creek suggests the listing for habitat alterations could be warranted. Temperature monitoring and source assessment results were uncertain. It does not appear that riparian shade conditions are likely to heat Pintlar Creek, but irrigation withdrawals and water use may impact temperature conditions. A more detailed irrigation assessment would be needed to determine if reduced water volume causes temperatures above Montana's standard and if irrigation water conservation management activities have been implemented. A temperature TMDL will not be completed at this time but a follow up monitoring strategy is identified in **Section 11.0** to determine if a temperature TMDL is necessary.

Table 5-14: Summary of targets and existing conditions in Pintlar Creek.

<table>
<tr><th>Pollutant</th><th>Parameter</th><th>Reach Name</th><th>Target or SI</th><th>Value/ Score</th><th>Target Column</th><th>Met target?</th></tr>
<tr><td rowspan="15">Sediment</td><td>Pebble Counts Percent fines (≤ 6 mm in riffles)</td><td>PC04</td><td>Target</td><td>19</td><td>≤ 22</td><td>Y</td></tr>
<tr><td>Pebble Counts Percent fines (≤ 2 mm in riffles)</td><td>PC04</td><td>Target</td><td>17</td><td>≤ 18</td><td>Y</td></tr>
<tr><td rowspan="2">Percent Fines Grid (≤ 6 mm pool tailout)</td><td>PC04</td><td rowspan="2">Target</td><td>M = 81
25th = 73</td><td rowspan="2">Median ≤ 80
25th percentile ≤ 27</td><td>**N**</td></tr>
<tr><td>PC04B</td><td>M = 64
25th = 64</td><td>**N**</td></tr>
<tr><td rowspan="2">Pool frequency</td><td>PC04</td><td rowspan="2">Target</td><td>7</td><td rowspan="2">≤ 8</td><td>Y</td></tr>
<tr><td>PC04B</td><td>**15**</td><td>**N**</td></tr>
<tr><td rowspan="2">Width-to-depth ratio</td><td>PC04</td><td rowspan="2">Target</td><td>75^{th} = 14
M = 14</td><td rowspan="2">75th percentile ≤ 20
Median ≤ 14</td><td>Y</td></tr>
<tr><td>PC04B</td><td>75^{th} = 11
M = 9</td><td>Y</td></tr>
<tr><td rowspan="2">Understory shrub cover along greenline</td><td>PC04B</td><td rowspan="2">Target</td><td>25^{th} = 46
M = 63</td><td rowspan="2">25th percentile ≥ 32
M ≥ 58</td><td>Y</td></tr>
<tr><td>PC04</td><td>25^{th} = 69
M = 75</td><td>Y</td></tr>
<tr><td>Eroding bank (ft^2)</td><td>PC04B</td><td>SI</td><td>**297**</td><td>≤ 212</td><td>**N**</td></tr>
<tr><td>Macroinvertebrates</td><td colspan="5">No recent information</td></tr>
<tr><td>Human Sources Present</td><td colspan="5">Grazing and transportation systems present. Granitic geology may naturally influence sediment production.</td></tr>
</table>

5.14 Rock Creek

Rock Creek lies on the west side of the Upper Big Hole Valley and flows to the northeast. A recent restoration project restored the lower portion of Rock Creek so it now reaches the Big Hole River, but previously it was incorporated into irrigation ditches. The 303(d) List includes numerous causes of impairment for Rock Creek, including siltation as a pollutant requiring a TMDL. Nutrient conditions in Rock Creek will not be addressed in this document although they are likely an issue in Rock Creek. Nutrient conditions will be addressed in future TMDL efforts. Sediment and associated habitat listings will be addressed by this document.

5.14.1 Sediment

Pertinent sediment related information for Rock Creek includes narrative descriptions provided by the USFS, aerial photo assessments, and field assessments during 2004. Land ownership in the drainage includes a mixture of state, federal, and private lands. USFS holdings account for 38 percent of the watershed in headwater portions. After leaving the National Forest, Rock Creek flows through patches of BLM land, then state lands. The majority of the Rock Creek watershed (52%) lies on private, agricultural lands in the valley.

Land uses on the forested portions of the watershed include timber harvest, recreation, and livestock grazing and associated roads with these activities. Nearly 11 miles of road occur on USFS lands. Road density varies across the basin with 55 percent being roadless, 27 percent having low road density, 16 percent with moderate road density, and 2 percent with high road density. The greatest concentrations of roads occur along intermittent tributaries, Dry and Mifflin creeks. Road crossings include one crossing on a perennial stream and three crossings on intermittent tributaries, all composed of native materials. In addition, a trail system facilitates recreational access to the upper basin. Logging has occurred on about 6 percent of USFS lands with approximately 60 percent of trees removed on these 861 acres. Nearly 80 percent of the USFS lands are in a grazing allotment although a small portion of this area is suitable for grazing.

Investigations conducted by the USFS in the 1980s and early 1990s indicated a range of conditions in the upper Rock Creek drainage. Stream assessments in 1989 found Rock Creek to be a stable, functioning B3 channel (Bengeyfield 1998). Dry Creek, an intermittent tributary of Rock Creek, is a potential source of sediment loading to Rock Creek. Assessments indicate a non-functioning reach with an overly wide, unstable channel. These conditions were a result of former livestock grazing practices, which were more damaging than the current management practices.

Fisheries data indicate Rock Creek may be a priority for water quality planning. Sampling in 1998 found westslope cutthroat trout and brook trout. The tendency of brook trout to displace the native westslope cutthroat trout, especially in degraded streams (Shepard et al. 1998), is an important consideration for Rock Creek.

Assessments of aerial imagery during TMDL planning provide a spatially extensive view of conditions along the entire length of Rock Creek. Timber harvest to the stream channel occurred in portion of the montane reaches. This evaluation indicated riparian degradation and dewatering are present along this valley reaches. Riparian shrub density rated as sparse to moderate for many of the valley reaches. Hay production encroached on the stream, a practice that reduces shrub cover and therefore the functional attributes of riparian vegetation.

Reconnaissance investigations during 2004 confirm results of the aerial photo assessment for valley portions of Rock Creek. Field notes describe a lack of willows, with sedges being the dominant riparian vegetation. Some banks were actively eroding due to trampling by livestock. A lack of stream flow was attributable for channel narrowing. Instream habitat was also degraded. Fine sediment filled in pools and undercut bank habitat was lost due to trampling. Combined, these observations suggest that livestock grazing and dewatering were responsible for increasing loading of sediment to streams and decreasing sediment transport efficiency, which can reduce the stream's ability to support its beneficial uses.

Sediment TMDL monitoring assessments during 2004 on the valley portions of Rock Creek provide additional evidence of sediment problems. Width-to-depth ratios were elevated at one site compared to reference reaches indicating lateral adjustments in channel morphology and a decreased ability to transport fine sediment (**Table 5-15**). The increase in width-to-depth ratios may have been due to reduction in the functional attributes of riparian vegetation. Shrub cover was considerably lower than reference reaches and bare ground comprised a relatively large component of streambanks at this same site. Bank erosion varied, but appeared to meet targets. Pool numbers were low at one of the measured sites (**Table 5-15**). Percent fines measured through both pebble counts in riffles were found to be high at one site and the percent fines grid measurement in pools was high at the other site.

Aquatic insect communities are comparable to reference conditions at upper site on BLM land, but do not meet targets at a site in the Big Hole Valley. Rock Creek has brown, rainbow and brook trout populations (MFISH). There are several tributaries of Rock Creek that also contain populations of these three salmonid species.

5.14.2 Summary of Sediment Conditions and Conclusions

Although stream channel geometry and bank erosion are not severely impacted, it appears that riparian shrub growth is depressed. Fine sediment accumulation in pool and riffle areas likely impact aquatic insect and fish communities by filling critical habitat areas. Human influenced sources, mostly grazing and transportation systems, are present. A sediment TMDL will be pursued.

Table 5-15: Summary of sediment targets and existing conditions in Rock Creek.

Pollutant	Parameter	Reach Name	Target or SI	Value/ Score	Target Column	Met target?
Sediment	Pebble Counts Percent fines (≤ 6 mm in riffles)	RO04	Target	**32**	≤ 22	**N**
		RO06		20		Y
	Pebble Counts Percent fines (≤ 2 mm in riffles)	RO04	Target	**19**	≤ 18	**N**
		RO06		13		Y
	Percent Fines Grid (≤ 6 mm pool tailout)	RO04	Target	M = 24 25^{th} = 20	Median ≤ 80 25th percentile ≤ 27	Y
		RO06		**M = 98** **25^{th} = 97**		**N**
	Pool frequency	RO04	Target	5	≤ 8	Y
		RO06		**13**		**N**
	Width-to-depth ratio	RO04	Target	**75th = 26** M = 14	75th percentile ≤ 20 Median ≤ 14	**N**
		RO06		75^{th} = 15 M = 13		Y
	Understory shrub cover along greenline	RO04	Target	**25th = 18** **M = 22**	25th percentile ≥ 32 M ≥ 58	**N**
		RO06		**25th = 13** **M = 19**		**N**
	Eroding bank (ft^2)	RO04	SI	31	≤ 212	Y
		RO06		150		Y
	Macroinvertebrates	Aquatic insect communities are comparable to reference conditions at upper site on BLM land but do not meet targets at a site in the Big Hole Valley.				
	Human Sources Present	Grazing and transportation systems are present.				

5.15 Ruby Creek

The headwaters of Ruby Creek lie in the Beaverhead Mountains on the west side of the upper Big Hole River planning area. The majority of its 12-mile length is on the Beaverhead National Forest. The lower 4 miles flow through private lands before its confluence with Trail Creek where it becomes the North Fork Big Hole River. Ruby Creek is on the 303(d) List for several probable causes of impairment. Probable causes of impairment include sedimentation/siltation, the only listed pollutant, and several associated types of pollution including physical habitat substrate alterations, alteration instreamside vegetation, and low flow alterations. Sediment and related habitat conditions will be addressed in this section.

5.15.1 Sediment

USFS stream narratives describe conditions on the USFS lands which may possibly affect sediment production. Over 90 percent of the Ruby Creek watershed lies on USFS lands. These lands have a long history of multiple uses with effects still lingering. Roads and trails are significant features. These parallel the stream for much of its length. Road density varies in the basin with 49 percent lacking roads, 31 percent having low road density, 16 percent having moderate road density, and 4 percent with high road density.

Livestock grazing is also a significant use with grazing allotments covering most of the watershed. Livestock grazing in the past has resulted in severe degradation of riparian areas and channel stability on the federal lands. Several restoration projects have targeted this degradation and have been successful in restoring bank and channel stability.

Historic placer mining is another influence on channel morphology in Ruby Creek. The effects of this were probably severe at one time; however, these areas have recovered. The USFS no longer considers mining a significant type of impact on Ruby Creek.

Aerial photo analyses indicate variable conditions along the length of Ruby Creek. Several of the montane reaches had no identifiable impacts, although timber harvest and forest roads were apparent near other reaches. Irrigation withdrawals were observable in most of the valley portions of the stream. Riparian conditions were variable with a tendency for greatly reduced shrub cover in the lower reaches of Ruby Creek.

TMDL sediment survey results varied by site but indicate a sediment TMDL is needed. Width-to-depth ratios were low and similar to reference indicating the channel was relatively narrow and deep. In addition, high entrenchment ratios indicated assessed reaches had easy access to the floodplain during high flows. Measures of vegetation are generally consistent with riparian vegetation conditions at reference sites except, slightly less vegetation than reference at both the upper and lower site (**Table 5-16**). The extent and severity of bank erosion in the middle assessed reach on Ruby Creek was a concern. This reach exceeded the average area of eroding banks on reference reaches by a considerable margin.

Measures of surface fines suggested siltation may be impacting beneficial uses in some locations within Ruby Creek. Fines < 6mm measured in riffles at the lowest site were high (**Table 5-16**). Median levels of fine sediment in pool tailout areas at the lower sites were above targets. Fine sediment accumulation in riffles and pools in the lower sections of Ruby Creek may be impacting aquatic life and the fishery.

An aquatic insect assessment resulted in low diversity and therefore did not meet criteria for a healthy insect community. Ruby Creek has several fish species, including brook trout, burbot, longnose sucker, mottled sculpin and westslope cutthroat trout (MFISH). There are various tributaries within Ruby Creek that also contain the same fish species.

Table 5-16: Summary of sediment targets and existing conditions in Ruby Creek.

Pollutant	**Parameter**	**Reach Name**	**Target or SI**	**Value/ Score**	**Target Column**	**Met target?**
Sediment	Pebble Counts Percent fines (≤ 6 mm in riffles)	RC04	Target	2	≤ 13	Y
		RC07		15	≤ 22	Y
		RC08		**26**		**N**
	Pebble Counts Percent fines (≤ 2 mm in riffles)	RC04	Target	0	≤ 13	Y
		RC07		11	≤ 18	Y
		RC08		18		Y
	Percent Fines Grid (≤ 6 mm pool tailout)	RC04	Target	M = 4 25^{th} = 1	Median ≤ 51 25th percentile ≤ 42	Y
		RC07		M = 50 **25th = 42**	Median ≤ 80 25th percentile ≤ 27	**N**
		RC08		M = 54 **25th = 48**		**N**
	Pool frequency	RC04	Target	5	≤ 6	Y
		RC07		6	≤ 8	Y
		RC08		4		Y
	Width-to-depth ratio	RC04	Target	**75th = 16** **M = 15**	75th percentile ≤ 13 Median ≤ 10	**N**
		RC07		75^{th} = 15 M = 11	75th percentile ≤ 20 Median ≤ 14	Y
		RC08		75^{th} = 14 M = 10		Y
	Understory shrubs along green line	RC04	Target	**25th = 34** M = 45	25th percentile ≥ 36 M ≥ 41	**N**
		RC07		25^{th} = 52 M = 57	25th percentile ≥ 32 M ≥ 58	Y
		RC08		25^{th} = 36 **M = 47**		**N**
	Eroding bank (ft^2)	RC04	SI	95	≤ 113	Y
		RC07		**869**	≤ 212	**N**
		RC08		196		Y
	Macroinvertebrates	One sample did not meet supplemental indicator metrics.				
	Human Sources Present	Historic mining, silviculture, transportation and grazing systems are present. Granitic geology may also affect sediment production.				

5.15.2 Summary of Sediment Conditions and Conclusions

Comparison of conditions in and along Ruby Creek to sediment targets and supplemental indicators provides support for pursuing sediment TMDL development (**Table 5-16**). While the general condition of the watershed has been improving over the past few decades, fine sediment targets are not met in the lower portions of Ruby Creek and may be impacting fish and aquatic insects. Current and historic human caused sediment sources are present. A sediment TMDL will be pursued.

5.16 Steel Creek

Steel Creek is a tributary of the Big Hole River originating in the Pioneer Mountains on the east side of the upper Big Hole River valley. The upper, forested portion of the watershed lies on the Beaverhead Deerlodge National Forest. The remaining 22 percent of the watershed is on lower elevation private lands. Steel Creek has been identified on prior 303(d) lists for sediment as a cause of impairment. Currently listed pollutants include cadmium, copper and phosphorus. The latest 303(d) List includes the following potentially sediment related pollution categories: alteration instream side vegetation, physical substrate habitat alterations, other anthropogenic substrate alterations and low flow alterations. Eight identified abandoned mines may be responsible for metals loading to Steel Creek.

5.16.1 Sediment

Stream narratives prepared by the Beaverhead National Forest (BNF) describe land uses and stream conditions for the forested portions of the watershed. Roads are a significant feature with 20 percent of the USFS portion of the hydrologic unit rated as having a high road density, some of which encroaches within the riparian buffer. Livestock grazing occurs primarily along tributary streams on USFS lands. Timber harvest has been limited with only 2 percent of USFS lands.

Sediment TMDL monitoring results support the determination that fine sediment impacts beneficial uses, at least for the lower reaches of this stream. In contrast, the assessed reaches on or near the USFS lands met most comparisons to reference reaches although did not fully meet sediment targets for stream bed sediments.

Width-to-depth and entrenchment ratios deviated substantially from reference on the lower assessed reach on Steel Creek (**Table 5-17**). Width-to-depth ratios approached or were greater than the threshold for “very high” width-to-depth (Rosgen 1996). In addition, the median entrenchment ratio for this reach was at the limit between entrenched and moderately entrenched. Together, these results indicate an overly wide channel with limited access to its floodplain. This scenario relates to sediment impact in that the overly wide channel has less sediment transport capacity, while the entrenchment ratio indicates the stream exerts greater shear stress on its banks during high flows, thereby increasing the potential for streambank erosion.

Riparian vegetative characteristics on this lowest reach of Steel Creek also showed indications of impact. Understory shrub cover was exceedingly low on both line transects and along the green line with less than 5 percent of cover comprised of this vegetation type (**Table 5-17**). Similarly, bare ground comprised a considerable proportion of both perpendicular line transects and green line samples, and was substantially greater on reference reaches. These results suggest that a lack of vegetative cover reduces bank protection resulting in banks that are more erodible compared to reaches with less impacted riparian cover. The survey of eroding banks provided additional indication that near stream sediment sources are higher than expected. Over 800 ft^2 of eroding bank occurred within the high category of erodibility. In contrast, reference reaches had on average about 200 ft^2 of eroding banks.

5.16.2 Metals (copper and cadmium)

Steel Creek is listed for likely impairment on Montana's 2006 303(d) List due to elevated copper and cadmium concentrations in grab samples collected in the early 1980s. Although there are mining sources in the watershed, a significant amount of uncertainty remained on the appropriateness of this listing for several reasons (**Appendix K**, **Map 3)**. First, detection limits from older analyses were often too high for reliable application of the numeric standards and data reliability at levels near the standard is questionable. This uncertainty results in an increased probability of false violations when using data from this vintage. In addition, data currency, or the extent to which these data represented current conditions, was unknown.

Because of the uncertainty surrounding the potential for copper to impair beneficial use support in Steel Creek, the DEQ undertook additional sampling of water and sediment chemistry during 2004. Copper was undetected in water samples during 2004. Copper concentrations fall below the lowest evaluated effect level for benthic invertebrates (NOAA SQIRTs) indicating low risk to benthic organisms in contact with these substrates. Also, the DEQ's abandoned mine monitoring database indicates a sample collected below Clara mine in a small tributary during the 1990s may be above standards but the data is flagged indicating the sample should be considered an estimation because of lab quality assurance issues. This tributary does not usually express surface water to Steel Creek and the mine is a long distance from the Creek. Because of the uncertainty of data from the 1980s and the low copper concentrations found in Steel Creek during the 2004 monitoring, a copper TMDL will not be completed at this time.

Because of the uncertainty surrounding the potential for cadmium to impair beneficial use support in Steel Creek, the DEQ undertook additional sampling of water and sediment chemistry during 2004. Cadmium was undetected in all 2004 TMDL and 1990's abandoned mine water samples. Cadmium concentrations were above the lowest evaluated effect level for benthic invertebrates (NOAA SQIRTs) indicating there could be a slight risk to benthic organisms in contact with these substrates. The sediment samples were below probable effects levels that would likely exert toxic responses. Because of the uncertainty of data from the 1980s and the low copper concentrations found during the 2004 monitoring, a cadmium TMDL will not be completed at this time.

5.16.3 Nutrients

Nitrogen and phosphorus levels are above targets near the confluence with the Big Hole River (**Table 5-17**). Chlorophyll may be below targets because substrates algae would grow on in this area are smothered due to sedimentation. TMDL sediment monitoring results indicate that riparian filtering function is impacted and bank erosion as well as bare ground are elevated in this area. Grazing and hay production impacts increase in a downstream direction and nutrient conditions do likewise. Nutrient TMDLs will be provided in **Section 9**.

5.16.4 Summary of Sediment, Nutrient and Metals Conditions and Conclusions

Comparison of conditions in and along lower portions of Steel Creek to sediment targets and supplemental indicators provides support for pursuing sediment TMDL development (**Table 5-16**). Implementing improved grazing management practices would likely improve sediment and habitat conditions along most unforested portions of Steel Creek. Current and historic human caused sediment sources are present. A sediment TMDL will be pursued.

Sampling during 2004 results indicated low copper concentrations in Steel Creek sediment and water samples. Cadmium sampling results indicated slightly elevated levels of cadmium in sediments but no exeedences of water quality standards. These results indicate that metals TMDLs are likely not needed and will not be pursued at this time. Nutrient conditions in the lower reaches of Steel Creek are elevated and sources are apparent. Nutrient TMDLs will be pursued in this TMDL planning effort.

Table 5-17: Summary of targets and existing conditions in Steel Creek. Non-detectable values indicated by ND.

Pollutant	Parameter	Reach Name	Target or SI	Value/ Score	Target Column	Met target?
Sediment	Pebble Counts Percent fines (≤ 6 mm in riffles)	SC02	Target	NA		
		SC03		**52**	≤ 22	**N**
		SC06		**26**		**N**
	Pebble Counts Percent fines (≤ 2 mm in riffles)	SC02	Target	NA		
		SC03		**32**	≤ 18	**N**
		SC06		**25**		**N**
	Percent Fines Grid (≤ 6 mm pool tailout)	SC02	Target	**M = 100** **25th = 100**	Median ≤ 51 25th percentile ≤ 42	**N**
		SC03		**M = 77** **25th = 69**	Median ≤ 80 25th percentile ≤ 27	**N**
		SC06		M = 46 **25th = 42**		**N**
	Pool frequency (Bank full width/pool)	SC02	Target	Not Applicable		
		SC03		**21**	≤ 8	**N**
		SC06		**10**		**N**
	Width-to-depth ratio	SC02	Target	75th = 5 M = 4	75th percentile ≤ 13 Median ≤ 10	Y
		SC03		75th = 8 M = 6	75th percentile ≤ 20 Median ≤ 14	Y
		SC06		**75th = 35** **M = 33**		**N**
	Understory shrubs along green line (%)	SC02	Target	25th = 75 M = 76	25th percentile ≥ 36 Median ≥ 41	Y
		SC03		25th = 49 M = 55	25th percentile ≥ 32 Median ≥ 58	Y
		SC06		**25th = 0** **M = 0**		**N**
	Eroding banks (ft^2)	SC02	SI	NA		
		SC03		**259**	≤ 212	**N**
		SC06		**818**		**N**
	Macroinvertebrates	No recent results available near most impacted areas.				
	Human Sources Present	Transportation and grazing systems present				

Table 5-17: Summary of targets and existing conditions in Steel Creek. Non-detectable values indicated by ND.

Pollutant	Parameter	Reach Name	Target or SI	Value/ Score	Target Column	Met target?
Copper	Benthic sediments	UBHSTEE 01 8/27/2004	Target	17.1	< 35 mg/kg	Y
		UBHSTEE 02 8/27/2004	Target	11.7	< 35 mg/kg	Y
	Water column	UBHSTEE 01 UBHSTEE 02 UBHSTEE 03 UBHSTEE 04 5/18/2004	Target	All NDs*	Acute = 4 and Chronic = 3 ug/L @ 25 mg/L hardness	Y
	Water column	UBHSTEE 01 UBHSTEE 02 8/27/2004	Target	All NDs*		Y
Cadmium	Benthic sediments	UBHSTEE 01 8/27/2004	Target	**1.36**	< 0.6 mg/kg	**N**
		UBHSTEE 02 8/27/2004	Target	**1.53**	< 0.6 mg/kg	**N**
	Water column	UBHSTEE 01 UBHSTEE 02 UBHSTEE 03 UBHSTEE 04 5/18/2004	Target	All NDs*	Acute = 0.52 and Chronic = 0.1 ug/L @ 25 mg/L hardness	Y
	Water column	UBHSTEE 01 UBHSTEE 02 8/27/2004	Target	All NDs*		Y
Metals Sources	Abandoned mines present					

Table 5-17: Summary of targets and existing conditions in Steel Creek. Non-detectable values indicated by ND.

Pollutant	Parameter	Reach Name	Target or SI	Value/ Score	Target Column	Met target?
Nutrients	Chlorophyll *a*	8/27/2004 SC02	target	12.3**	< 150 mg/m^2	**N**
		8/27/2004 SC05		49.7**		**N**
		8/27/2004 SC06		64.3**		**Y**
	Total Nitrogen	8/27/2004 SC02	target	ND*	< 320 ug/L	Y
		8/27/2004 SC05		ND*		Y
		8/27/2004 SC06		**600**		**N**
	Total Phosphorous	8/27/2004 SC02	target	11	< 49 ug/L	Y
		8/27/2004 SC05		17		Y
		7/1/1981 SC06		**90**		**N**
		9/28/1982 SC06		**220**		**N**
		8/27/2004 SC06		**118**		**N**
	Dissolved Oxygen		SI	2 of 17 samples collected from 1972-1978 were below standards		
	Understory shrubs along green line (%)	SC02	SI	25th = 75 M = 76	25th percentile ≥ 36 Median ≥ 41	Y
		SC03		25th = 49 M = 55	25th percentile ≥ 32 Median ≥ 58	Y
		SC06		**25th = 0 M = 0**		**N**
	Shrubs along transect (%)	SC02	SI	25th = 78 M = 76	25th percentile ≥ 42 Median ≥ 64	Y
		SC03		**25th = 15 M = 30**	25th percentile ≥ 20 Median ≥ 48	**N**
		SC06		**25th = 0 M = 0**		**N**
	Bare ground along transect (%)	SC02	SI	M = 0	Median ~ 0	Y
		SC03		M = 0		Y
		SC06		**M = 17**		**N**
	Macroinvertebrates	The aquatic insect community metrics do not meet thresholds.				
	Human Sources	Grazing and hay production sources are present.				

NA = no visually eroding banks
ND = Under detection limit
** Estimated values due to sampling quality assurance review

5.17 Swamp Creek

Swamp Creek is a tributary of the Big Hole River flowing to the northeast from the west side of the basin. Unlike other streams in the watershed, Swamp Creek originates in the valley and lacks headwaters in the Beaverhead National Forest. Swamp Creek is identified in the most recent 303(d) List as being impaired due to sedimentation/siltation, nitrogen, phosphorus, low flow alterations and alteration instream side vegetation. The sediment and associated habitat listings will be addressed in this document but nutrient listings are not addressed due to their recent listing status.

5.17.1 Sediment

Results of the aerial photo assessment confirmed disturbances associated with land use. This included lack of channel integrity due to diminished stream flows and riparian degradation, presumably from livestock grazing. Density of riparian vegetation varied from moderate to sparse with differences in livestock management resulting in abrupt changes in riparian cover at fence lines.

The TMDL aerial photo assessment described several categories of disturbance with potential to contribute to siltation in Swamp Creek. Multiple flow diversions resulted in a loss of channel definition for significant portions of this stream. In addition, livestock grazing practices varied along the length of stream resulting in abrupt changes in riparian condition at fence lines. Sparse riparian shrub cover characterized significant portions of this stream.

Groundwater inputs are a significant portion of the flow in this stream and flood irrigation practices in the basin have possibly increased flows above natural. As the name Swamp Creek implies, this stream’s potential geomorphology may be different from snowmelt driven streams typical of the region.

TMDL sediment monitoring results varied between the two reaches assessed on Swamp Creek. In general, the upper reach had intact riparian and channel characteristics but pool frequency was low compared to reference reaches. The lower assessed reach had high width-to-depth ratios, low shrub cover, and high proportions of bare ground along the green line (**Table 5-18**). Measures of substrate fines, both in riffles and pools were usually above targets based on reference conditions and also above thresholds likely to impact aquatic life (**Table 5-18**).

The aquatic insect community metrics scored below their assigned thresholds indicating an impacted biological condition. The fish found in Swamp Creek include arctic grayling, brook trout, burbot, longnose dace, longnose sucker, mottled sculpin, mountain sucker, mountain whitefish, rainbow trout and white sucker (MFISH).

Table 5-18: Summary of targets and existing conditions on Swamp Creek. Non-detectable values indicated by ND*.

Pollutant	Parameter	Reach Name	Target or SI	Value/ Score	Target Column	Met target?
Sediment	Pebble Counts Percent fines (≤ 6 mm in riffles)	SW03	Target	**25**	≤ 22	**N**
		SW10		**27**		**N**
	Pebble Counts Percent fines (≤ 2 mm in riffles)	SW03	Target	**21**	≤ 18	**N**
		SW10		**24**		**N**
	Percent Fines Grid (≤ 6 mm pool tailout)	SW03	Target	**M = 91** **25th = 71**	Median ≤ 80 25th percentile ≤ 27	**N**
		SW10		M = 16 25th = 10		Y
	Pool frequency	SW03	Target	**13**	≤ 8	**N**
		SW10		6		Y
	Width-to-depth ratio	SW03	Target	75th = 13 M = 7	75th percentile ≤ 20 Median ≤ 14	Y
		SW10		**75th = 30** **M = 28**		**N**
	Understory shrubs along green line	SW03	Target	**25th = 38** M = 43	25th percentile ≥ 32 Median ≥ 58	**N**
		SW10		**25th = 2** **M = 2**		**N**
	Eroding bank (ft^2)	SW03	SI	NA	≤ 212	NA
		SW10		**1624**		**N**
	Macroinvertebrates	Two aquatic insect assessments indicate poor community health and do not meet thresholds.				
	Human Sources Present	Grazing and transportation systems present				

NA = no visually eroding banks

5.17.2 Summary of Sediment Conditions and Conclusions

Available information provides support for the need of a sediment TMDL to address nutrients and siltation in Swamp Creek. Nevertheless, this stream is unique in the upper Big Hole River planning area and probably has different potential than other streams. A major factor influencing this stream is its hydrology. It functions more as a spring creek than a snowmelt driven stream. Spring creeks tend to be more productive and have higher levels of fine sediment due to a lack of flushing flows. Therefore, TMDL planning efforts must incorporate these considerations through the adaptive management approach to ensure that targets are appropriate for Swamp Creek.

5.18 Schultz Creek

Schultz Creek is a small montane stream lying on the west side of the upper Big Hole River planning area, mostly on the Beaverhead National Forest. This stream flows for three miles until its confluence with Johnson Creek. Schultz Creek is on Monana's 303(d) List with sedimentation/siltation as a probable cause of impairment and silvicultural practices as the probable source of impairment.

According to stream narratives provided by the USFS, land use activities in the Schultz Creek drainage include timber harvest and roads. A road parallels the stream for much of its length but is usually about 300 feet from the stream, which for the most part, provides a buffer that filters out sediment produced from the road. Fish surveys found westslope cutthroat trout and tailed frogs. Most of the watershed burned during 2000 except for the areas that were harvested in the 1980-1990s.

5.18.1 Sediment

Sediment TMDL monitoring and associated field observations support the conclusion that Schultz Creek does not need a sediment TMDL. Representative measures of channel morphology, riparian vegetative cover, and substrate fines indicated a functioning stream (**Table 5-19**). Shrub cover was low; however, conifers comprised the streamside vegetation and likely shaded the undercanopy area. In addition, field notes report substantial recruitment of large woody debris forming habitat features for fish. Many of the riparian areas were burned severely in 2000.

Aquatic insect samples collected from Schultz Creek by the DEQ indicate a healthy community when compared to regional reference conditions. Schultz Creek contains populations of westslope cutthroat and westslope cutthroat x yellowstone cutthroat trout hybrids (MFISH).

Table 5-19: Summary of sediment targets and existing conditions in Schultz Creek.

Pollutant	Parameter	Reach Name	Target or SI	Value/ Score	Target Column	Met target?
Sediment	Pebble Counts Percent fines (≤ 6 mm)	SH01	Target	13	≤ 13	Y
	Pebble Counts Percent fines (≤ 2 mm)	SH01	Target	13	≤ 13	Y
	Percent Fines Grid (≤ 6 mm pool tailout)	SH01	Target	M = 8 25^{th} = 5	Median ≤ 10 25th percentile ≤ 5	Y
	Pool frequency	SH01	Target	5	NA	NA
	Width-to-depth ratio	SH01	Target	75^{th} = 13 M = 13	75th percentile ≤ 15 Median ≤ 13	Y
	Percent understory shrub cover along green line	SH01	Target	75^{th} = 0 M = 0	NA	NA
	Eroding bank (ft^2)	SH01	SI	0	≤ 113	
	Macroinvertebrates	Aquatic insect community assessment metrics met criteria for a healthy community.				
	Potential Human Sources Present	Silviculture and unpaved road systems				

NA = Not applicable

5.18.2 Summary of Sediment Conditions and Conclusions

Although timber harvest and road development are potential sources of sediment loading to Schultz Creek, the available information describes a healthy montane stream supporting a native fishery. All instream or riparian based sediment targets and indicators are met. A sediment TMDL for Schultz Creek will not be completed at this time.

5.19 Tie Creek

Tie Creek is a montane tributary of the North Fork Big Hole River on the west side of the basin. It flows about 14 miles with all but the last 2 miles within the Beaverhead National Forest. Probable causes of impairment for Tie Creek include sedimentation/siltation, physical substrate habitat alterations and nitrogen. The sediment and associated habitat listings will be addressed in this document but nutrient listings are not addressed due to their recent listing status.

5.19.1 Sediment

Information allowing assessment of siltation in Tie Creek includes written watershed narratives, aerial photo assessments, and TMDL sediment sampling assessments. Stream narratives provided by the USFS describe potential human caused sediment sources. Tie Creek watershed has experienced substantial land use activities, although natural recovery and restoration activities by the USFS have reduced sediment production and delivery from its peak in the 1970s.

Beginning in the 1960s and continuing through the 1970s, timber harvest was significant with nearly 10 percent of the basin having 60 percent of its trees removed. Road construction accompanied timber harvest and roads and trails occur throughout the basin. Road density is higher than most other drainages in the upper Big Hole River planning area with 17 percent lacking roads, 31 percent having low road density, 30 percent having moderate road density, and 22 percent having high road density. Roads encroach within 300 feet of streams for 3.6 miles.

In response to concerns regarding sediment loading from roads, the USFS engaged in extensive road restoration activities in the early 1990s. Road treatments included installation of water bars, lining ditches with rocks, and placement of filter windrows at the toe of fill slopes. To reduce sediment delivery at road crossings, approaches were paved and some new cross-drain culverts were installed.

Livestock grazing is another land use on the National Forest that has resulted in sediment loading and channel alterations. In the 1980s, livestock grazing had resulted in destabilization of nearly 50 percent of streambanks, which caused channel widening. This caused high levels of embeddedness, including known spawning areas. During the mid 1990s, new, refined grazing management began on the USFS lands. The high degree of embeddedness decreased in subsequent decades, probably in response to implementation of BMPs, road improvements, and changes in grazing management.

Aerial photo analyses conducted during TMDL planning provide additional information pertaining to sediment pollution. Old clear cuts were apparent from aerial imagery. However, sensitive reaches within distinct valley portions appeared to have substantial shrub cover and a stable, sinuous channel.

Observations by DEQ personnel in 2001 provided additional insight into conditions in Tie Creek. Dense growth of young willows occupied much of the riparian area with mature shrubs being more scattered. Eroding banks were widespread at the upstream sampling site, but not the lower. Sand sized particles were a dominant gradation on the streambed.

Field observations during the 2004 sediment TMDL monitoring describe a riparian area recovering from past grazing practices. Willows were abundant but they were a relatively young stand. Beavers were apparently thriving in this reach and would likely increase pool habitat in the near future.

TMDL sediment and habitat monitoring suggest implementation of BMPs and restoration efforts have affected recovery in Tie Creek. The assessed reach had low width-to-depth ratio typical of a Rosgen E channel and was non-entrenched, indicating easy access to its floodplain during high flows. Shrub cover compared favorably to reference reaches with about 60 percent of both the green line and line transect comprised of shrubs (**Table 5-20**). Similarly, bare ground was rare suggesting vegetation protected banks from erosion. Slightly elevated bank erosion may be an artifact of past land use.

Pool habitat measures and proportions of surface fines provide information on the effect of in channel sediment on fisheries and aquatic life. Pool frequency was low compared to reference; however, this measure under represents pools as beavers had areas near this reach and should be considered a natural condition. High proportions of fine sediment were found in riffles, although fines in viewing buckets were relatively low (**Table 5-20**). This also could be related to beaver activity or past and present land use activities in the watershed.

Aquatic insect community metrics at two sites were slightly lower than criteria based upon regional expectations. Tie Creek has populations of brook, burbot, longnose dace, mottled sculpin and sucker.

5.19.2 Summary of Sediment Conditions and Conclusions

Although historic land use practices reportedly contributed considerable amounts of fine sediment to Tie Creek, subsequent recovery and restoration efforts have been successful in reducing sediment loading to streams. The existing conditions assessment indicates that fine sediment is at a level that may impact aquatic life and biological indicators are consistent with this assessment. Although, this existing conditions assessment does not indicate if the fine sediment conditions are lingering affects from existing and past management or from natural conditions such as granitic geology and beaver influences. A TMDL source assessment is provided in this document to investigate sediment sources more accurately and potentially provide allocations to those sources.

Table 5-20: Summary of sediment targets and existing conditions in Tie Creek.

Pollutant	Parameter	Reach Name	Target or SI	Value/ Score	Target Column	Met target?
Sediment	Pebble Counts Percent fines (≤ 6 mm in riffles)	TI02	target	**33**	**≤ 13**	**N**
	Pebble Counts Percent fines (≤ 2 mm in riffles)	TI02	target	**26**	**≤ 13**	**N**
	Percent Fines Grid (≤6mm pool tailout)	TI02	SI	M = 9 25^{th} = 6	Median ≤ 51 25th percentile ≤ 42	Y
	Pool frequency	TI02	SI	5	≤ 6	Y
	Width-to-depth ratio	TI02	target	75^{th} = 10 M = 9	75th percentile ≤ 13 Median ≤ 10	Y
	Understory shrub cover along greenline	TI02	target	25^{th} =49 M = 51	25th percentile ≥ 36 Median ≥ 41	Y
	Eroding banks (ft^2)	TI02	SI	**161**	≤ 113	**N**
	Macroinvertebrates	Aquatic insect community metrics are slightly lower than criteria based upon regional expectations.				
	Human Sources Present	Grazing, unpaved road and silviculture management are present.				

5.20 Trail Creek

The Trail Creek drainage is the largest montane watershed in the west side of the upper Big Hole River planning area. It originates along the Continental Divide and Idaho border then flows east to its confluence with the North Fork Big Hole River. The DEQ lists two segments of Trail Creek as impaired. The upper segment, which extends from its headwaters until its confluence with Joseph Creek, includes siltation and physical substrate habitat alterations as probable causes of impairment. The lower segment, which covers the remaining length of this stream, is listed for the same probable causes as the upper segment.

Trail Creek watershed is predominantly under management by the USFS with 91 percent of the basin within the Beaverhead National Forest. Eight percent of this watershed lies on private lands and less than 1 percent is on the Big Hole National Battlefield.

5.20.1 Sediment

The USFS also divides the Trail Creek watershed in its planning and management documentation. The upper portion is nearly entirely on USFS holdings, with only 0.4 percent lying on private lands. Land uses on this portion of the watershed include extensive roads, multiple use trails, and the related recreational opportunities. Road density varies across this portion of the watershed with 20 percent having no roads, 31 percent having low road density, and 31 percent and 18 percent having moderate and high road density respectively. Mining and logging have also occurred in the watershed. One known placer mine occurs in the drainage. During the 1970s and 1980s, nearly 11 percent of the drainage had 60 percent or more of the trees removed. Sediment inputs from timber harvest and associated activities were probably significant in the past.

Livestock grazing was traditionally a significant activity in this watershed; however, the USFS ceased grazing in the watershed in 2000. This management change, combined with natural recovery of logged areas, was attributable for improvements in riparian condition and reduced embeddedness.

Natural disturbance is another factor with potential to increase sediment loading and contribute to channel alterations in the Trail Creek watershed. The Gibbons Pass fire and Mussigbrod fire burned at least 16 percent of the watershed.

Roads are a significant factor in the lower Trail Creek watershed. Nearly 42 miles of roads occur on USFS lands with 18 percent having no roads, 22 percent having low road density, 33 percent having moderate road density, and 27 percent having high road density. Numerous road crossings occur in the drainage with 18 crossings over perennial streams and 29 crossings over intermittent streams. Road surfacing at crossing varies. Most crossings of perennial segments are asphalt with only six comprised of native materials. Intermittent road crossings are mostly of native materials with seven paved crossings and one gravel crossing. Road traction sanding along Highway 43 has potential for influencing Trail Creek as it parallels the stream for much of its length. Another road related source of sediment was an unauthorized channelization of Placer Creek associated with road construction, which delivered large amounts of sediment to Trail Creek in the past.

Stream assessments conducted by the USFS during 2000-2001 depict a stream influenced by wildfire but probably recovering from logging in the 1970s and 1980s and livestock grazing since exclusion in 2000. Assessed reaches showed evidence of past livestock use but were on an upward trend. Wildfire was often attributable for the highly mobile substrate in these E channels. Although not specifically mentioned in USFS descriptive narratives, the basin geology is probably also a factor in promoting a fine-grained streambed.

Aerial photo assessments conducted as part of TMDL planning provided information on geomorphology and land use in Trail Creek (Confluence et al. 2003). Geomorphology reflected landform with several reaches confined laterally by valley walls. Conifers comprised the riparian vegetation in these reaches. Several reaches occupying montane valleys had highly sinuous E channels with dense willows. Reach TC03 appeared to have experience riparian clearing; however, field investigations in 2004 indicated substantial recovery following removal of livestock. Timber harvest on adjacent hill slopes was apparent for much of Trail Creek.

Sediment TMDL monitoring provides more detailed instream sediment and habitat information on several reaches of Trail Creek. Of the four assessed reaches, three occupied montane valleys with dense stands of willows and a sinuous channel with low width-to-depth ratios (cross reference). The exception was reach TC08, which lies in a canyon reach with Highway 43 paralleling the stream for much of its length. Field notes suggest channelization by this highway contributed to habitat alterations in this reach of stream. In addition, given proximity of this road to Trail Creek, it is possible that road traction sanding is a source of sediment loading to Trail Creek.

Comparison of available data to numeric targets and supplemental indictors for Trail Creek indicate intact riparian and instream conditions for most reaches with a few exceptions (**Table 5-21**). Riparian shrubs on TC02 were below target; however, coniferous forest accounted for some of these apparent deficiencies. Reach TC08 also had considerable proportions of coniferous forest, which resulted in relatively low cover of riparian shrubs. Discrepancies between quality assurance replicates on TC08 were the result of beavers impounding the reach between site visits. Measured pool frequency generally met objectives (**Table 5-21**). Eroding banks were slightly high at a number of sites and could be related to human activities such as roads, historic grazing, or increase in water yields due to timber harvest or fire.

Most reaches failed to meet targets for percent fines measured with pebble counts or the grid counts in pools (**Table 5-21**). Nevertheless, these targets do not distinguish between natural or anthropogenic loading. Fire and natural sandy soils and geology are present but historic grazing, extensive unpaved roads, road sanding and past timber harvest may contribute to increased levels of fine sediment in a naturally sensitive watershed.

Aquatic insect communities have been assessed at five sites during 2001 and 2004. Most sites did not meet criteria for healthy aquatic insect communities (**Table 5-21**). Trail Creek contains populations of brook trout, burbot, longnose dace, longnose sucker, mottled sculpin, mountain whitefish and sculpin (MFISH). Trail Creek has an abundance of tributaries that contain a number of fish species.

Table 5-21: Summary of sediment targets and existing conditions for Trail Creek.

Pollutant	Parameter	Reach Name	Target or SI	Value/ Score	Target Column	Met target?
Sediment	Pebble counts percent fines (≤ 6 mm in riffles)	TC02	target	7	≤ 13	Y
		TC03		**42**		**N**
		TC07		**34**		**N**
		TC08		**29**		**N**
		TC08B		**28**		**N**
	Pebble counts percent fines (≤ 2 mm in riffles)	TC02	target	4	≤ 13	Y
		TC03		**27**		**N**
		TC07		**23**		**N**
		TC08		**19**		**N**
		TC08B		**23**		**N**
	Percent fines grid (≤ 6 mm pool tailout)	TC02	SI	25^{th} = 35 M = 46	25th percentile ≤ 42 Median ≤ 51	Y
		TC03		25^{th} = 14 M = 23		Y
		TC07		25^{th} = 43 **M = 71**		**N**
		TC08		**25th = 27** **M = 37**	25th percentile ≤ 5 Median ≤ 10	**N**
	Pool frequency	TC02	SI	5	≤ 6	Y
		TC03		**8**		**N**
		TC07		6		Y
		TC08		9	NA	NA
	Width-to-depth ratio	TC02	target	75^{th} = 13 M = 10	75th percentile ≤ 13 Median ≤ 10	Y
		TC03		75^{th} = 11 M = 9		Y
		TC07		75^{th} = 11 M = 10		Y
		TC08		**75th = 41** **M = 35**	75th percentile ≤ 15 Median ≤ 13	**N**
		TC08B		**75th = 22** **M = 22**		**N**
	Understory shrub cover along green line	TC02	target	**25th = 35** **M = 36**	25th percentile ≥ 36 Median ≥ 41	**N**
		TC03		25^{th} = 42 M = 45		Y
		TC07		25^{th} = 35 M = 40		Y
		TC08		25^{th} = 50 M = 56	NA	NA
		TC08B		25^{th} = 2 M = 7		NA
	Eroding bank (ft^2)	TC02	SI	36	≤ 113	Y
		TC03		**183**		**N**
		TC07		36		Y
		TC08		**327**		**N**
	Macroinvertebrates	1 of 5 samples met MMI 2 of 5 samples met O/E				
	Human Sources Present	Historic grazing, past timber harvest, and road sanding				

5.20.2 Summary of Sediment Conditions and Conclusions

Available information for Trail Creek confirms possible loading of sediment from several human activities. Past logging and roads may contribute sediment to Trail Creek and its tributaries. Road traction sanding is among the road related sources of sediment. In contrast, exclusion of livestock grazing since 2000 has resulted in recovery of riparian vegetation and its functional attributes but lingering sediment from grazing may be present in the stream. Sediment levels in Trail Creek are above targets that are likely to impact aquatic life and fish. A sediment TMDL source assessment will be pursued.

5.21 Warm Springs Creek

Warm Springs Creek is a second order tributary of the Big Hole River originating in the Pioneer Mountains on the east side of the basin (**Appendix K**, **Map 1**). The majority of the watershed lies on USFS lands with about 4 miles of channel flowing across private lands in the foothills and valley land type. Warm Springs Creek is named so because of thermal springs that enter the stream near Jackson. A portion of these springs are used for the Jackson Hot Springs Pool. DEQ monitoring personnel evaluated Warm Springs Creek in 2003 to meet requirements for updating the 303(d) listing. These data indicated sedimentation/siltation, nitrogen, phosphorus, and alteration instream side vegetation impaired beneficial uses. The nutrient listings were new to the 2004 list and the TMDL project had been initiated prior to this date, therefore nutrient listings are not addressed.

5.21.1 Sediment

Information allowing evaluation of sediment as a constraint on beneficial uses in Warm Springs Creek comes from a number of sources. These include stream narratives, aerial photo evaluations, and field investigations. Together, these confirm the appropriateness of this listing for Warm Springs Creek.

Livestock grazing is the major land use in the portions of the watershed within the national forest. Stream assessments by the USFS indicate livestock grazing has resulted in geomorphic shifts to the stream channel. Road density is low with 98 percent of USFS lands being “inventoried roadless”. Very little commercial timber harvest has occurred in the basin. The aerial photo analyses noted several types of impairment among reaches on Warm Springs Creek (Confluence 2003). Livestock grazing appeared to reduce riparian shrub cover and increase bank erosion for significant portions of this stream. Observed flow diversions may impact sediment transport.

TMDL monitoring field notes confirm the need for grazing BMPs to reduce sediment inputs to this stream. Two of the three assessed reaches were overly wide with vegetation removal and trampling indicated as the cause of channel alterations. Although grazing practices had not reduced shrub cover below targets, bare ground was prevalent suggesting limited bank protection during high flows. A survey of eroding banks found reaches on Warm Springs Creek to substantially exceed both area and erodibility ratings from reference reaches (**Table 5-22**). Despite high proportions of eroding banks, both pebble counts and pool tail monitoring results showed low levels of fines on the streambed (**Table 5-22**). Also, 303(d) List pebble count monitoring produced results lower than targets even though methods not the same as those used to derive sediment targets.

Aquatic insect communities appear to be mostly healthy. One metric at one site is moderately low but is likely influenced by natural hot springs. Warm Springs Creek contains populations of brook trout, burbot, longnose dace, longnose sucker, mottled sculpin, westslope cutthroat trout and westslope cutthroat x Yellowstone cutthroat trout hybrids.

The high proportion of eroding banks linked to livestock grazing practices suggests sediment loading is above natural, although sediment is not depositing or apparently affecting biological uses within the stream as it is transported. Because of this, a sediment TMDL will not be pursued at this time. Sediment production and habitat alteration does occur and restoration approaches to reduce sediment derived via bank erosion in the watershed should be pursued even though a TMDL is not needed. The TMDL allocation approach for the Upper Big Hole River will include addressing bank erosion in Warm Springs Creek.

Table 5-22: Summary of sediment targets and existing conditions for Warm Springs Creek.

Pollutant	Parameter	Reach Name	Target or SI	Value/ Score	Target Column	Met target?
Sediment	Pebble counts percent fines (< 6 mm in riffles)	WS07	target	6	≤ 13	Y
		WS10		1	≤ 22	Y
		WS11		11		Y
	Pebble counts percent fines (< 2 mm in riffles)	WS07	target	2	≤ 13	Y
		WS10		1	≤ 18	Y
		WS11		5		Y
	Percent fines grid (<6mm pool tailout)	WS07	SI	25^{th} = 2 M = 8	25th percentile ≤ 5 Median ≤ 10	Y
		WS10		25^{th} = 5 M = 6	25th percentile ≤ 27 Median ≤ 80	Y
		WS11		25^{th} = 5 M = 8		Y
	Pool frequency	WS07	target	3	NA	NA
		WS10		7	≤ 8	Y
		WS11		6		Y
	Width-to-depth ratio	WS07	Target	75^{th} = 30 M = 30	75th percentile ≤ 15 Median ≤ 13	N
		WS10		75^{th} = 15 M = 15	75th percentile ≤ 20 Median ≤ 14	Y
		WS11		75^{th} = 17 M = 7		Y
	Understory shrubs along greenline	WS07	target	25^{th} = 74 M = 79	NA	NA
		WS10		25^{th} = 50 M = 58	25th percentile ≥ 32 Median ≥ 58	Y
		WS11		25^{th} = 37 **M = 48**		**N**
	Eroding banks (ft^2)	WS07	SI	**243**	≤ 113	**N**
		WS10		**608**	≤ 212	**N**
		WS11		**1834**		**N**
	Macroinvertebrates	Aquatic insect communities appear to be mostly healthy. One metric at one site is moderately low but may be influenced by natural hot springs.				
	Human Sources Present	Limited roads, moderate grazing use, and limited past timber harvest				

5.21.2 Summary of Sediment Conditions and Conclusions

Available information for Warm Springs Creek confirms possible loading of sediment from grazing and haying activities. Instream sediment, pool, and aquatic insect monitoring indicates that the sediment derived from bank erosion is likely not affecting beneficial uses. A sediment TMDL is not pursued at this time although the Big Hole River sediment TMDL allocation strategy will consider Warm Spring Creek as a source of sediments.

SECTION 6.0
DESCRIPTION OF TMDL COMPONENTS

A TMDL is basically a loading capacity for a particular water body and refers to the maximum amount of a pollutant a stream or lake can receive and still meet water quality standards. A TMDL can also be thought of as a reduction in pollutant loading resulting in attainment of water quality standards. More specifically, a TMDL is the sum of waste load allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources and natural background sources. In addition, the TMDL includes a margin of safety (MOS) that accounts for the uncertainty in the relationship between pollutant loads and the pollutant conditions of the receiving stream. The allowable pollutant load must ensure that the water body being addressed by the TMDL will be able to attain and maintain water quality standards regardless of seasonal variations in water quality conditions, stream flows, and pollutant loading. TMDLs are expressed by the following equation:

$$TMDL = \Sigma WLA + \Sigma LA + MOS$$

Each of the following three sections of the document (**Sections 7 – 9**) are organized by the four pollutants of concern in the Middle and Lower Big Hole TPA: sediment, nutrients, metals, and temperature. Each section includes a source assessment process for that pollutant, relevant water quality targets, a comparison of existing conditions to targets, quantification of loading from identified sources, TMDLs, and allocations to sources. Although the way a TMDL is expressed may vary by pollutant, these components are common to all TMDLs, regardless of pollutant. The major components that go into TMDL development are described in detail below.

6.1 Establishing and Evaluating Targets

Because loading capacity is evaluated in terms of meeting water quality standards, quantitative water quality targets and supplemental indicators are developed to help assess the condition of the water body relative to the applicable standard(s) and to help determine successful TMDL implementation. This document outlines water quality targets for each pollutant of concern in the Upper and Middle Big Hole TPA. TMDL water quality targets help translate the applicable numeric or narrative water quality standards for the pollutant of concern. For pollutants with established numeric water quality standards, the numeric values are used as TMDL water quality targets. For pollutants with only narrative standards, the water quality targets help to further interpret the narrative standard and provide an improved understanding of impairment conditions. Water quality targets typically include a suite of in-stream measures that link directly to the impacted beneficial use(s) and applicable water quality standard(s). The water quality targets help define the desired stream conditions and are used to link each pollutant to impacted uses. This was completed in **Sections 4.0** and **5.0**. Targets also provide benchmarks to evaluate overall success of ongoing and future restoration activities.

6.2 Quantifying Pollutant Sources

All significant pollutant sources, including natural background loading, are quantified so that the relative pollutant contributions can be determined. Source assessments often have to evaluate the seasonal nature and ultimate fate of the pollutant loading since water quality impacts can vary throughout the year. The source assessment usually helps to further define the extent of the problem by putting human caused loading into context with natural background loading.

A pollutant load is usually quantified for each point source permitted under the Montana Pollution Discharge Elimination System (MPDES) program. Most other pollutant sources, typically referred to as nonpoint sources, are quantified by source categories such as unpaved roads and/or by land uses such as crop production or forestry. Alternatively, a sub-watershed, tributary, or source area approach can be used; whereby, most or all nonpoint sources in a sub-watershed or tributary are combined for quantification purposes.

The source assessments are performed at a watershed scale because all potentially significant sources of the water quality problems must be evaluated. The source quantification approaches may range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading (40CFR Section 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.

Figure 6-1 is a schematic diagram illustrating how numerous sources contribute to the existing load(s) and how a TMDL is determined by comparing the existing load(s) to that which will meet standards.

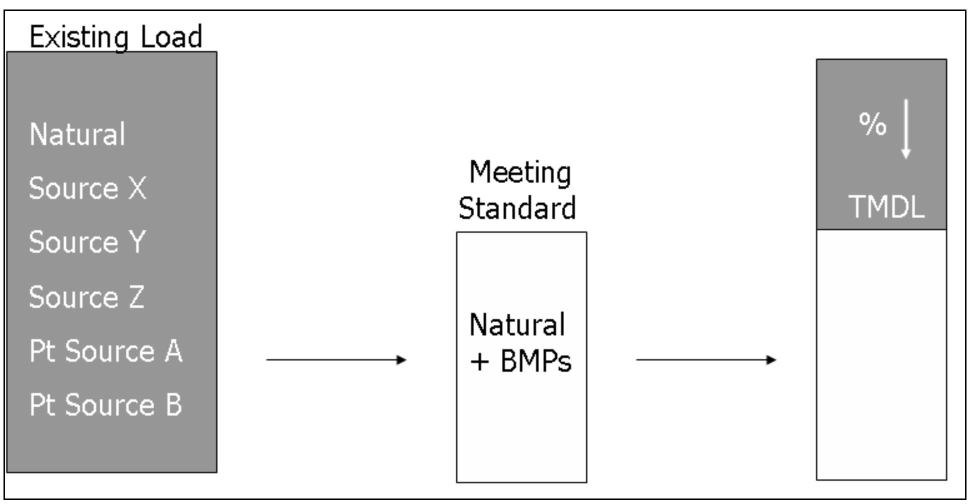


Figure 6-1: Schematic example of TMDL development.

6.3 Determining Allocations

Once the loading capacity (i.e. TMDL) is determined, that total must be divided, or allocated, among the contributing sources. Allocations are determined by quantifying feasible and achievable load reductions associated with the application of reasonable land, soil, and water conservation practices. Reasonable land, soil, and water conservation practices generally include BMPs, but additional conservation practices may be required to achieve compliance with water quality standards and restore beneficial uses. **Figure 6-2** contains a schematic diagram of how TMDLs are allocated to different sources using Waste Load Allocations (WLAs) for point sources and Load Allocations (LAs) for natural and nonpoint sources. Under the current regulatory framework for development of TMDLs, flexibility is allowed for specifying allocations in that *"TMDLs can be expressed in terms of either mass per time, toxicity, or other appropriate measure."* Allocations are typically expressed as a load, a percent reduction (from the current load), or as a surrogate measure, such as a percent increase in canopy density for temperature TMDLs. Load based allocations are typically desired if analysis allows; but, for certain pollutants such as nonpoint source temperature TMDLS, they may not be as useful as other more appropriate measures.

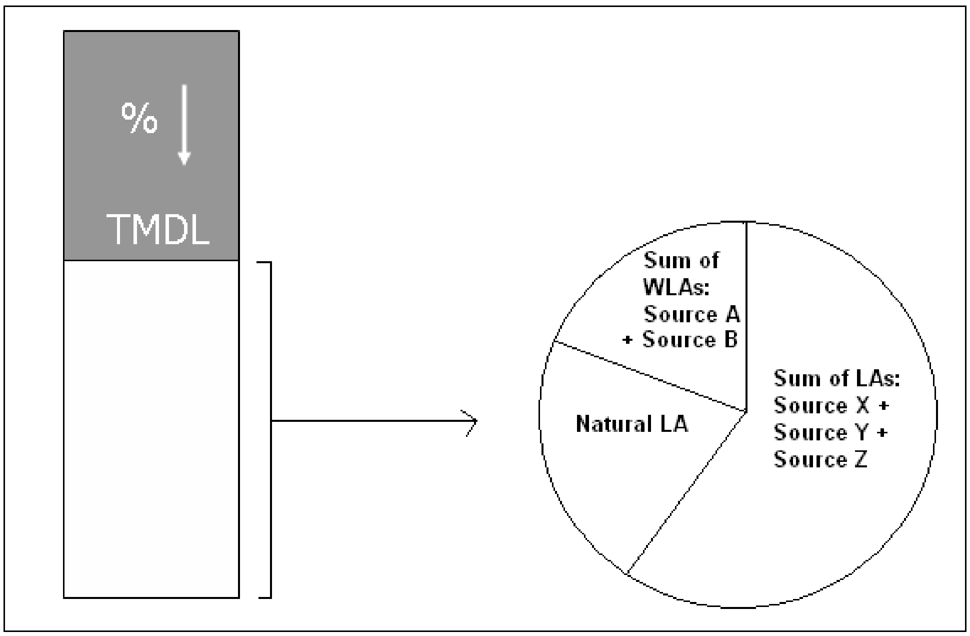


Figure 6-2: Schematic diagram of TMDL and allocations.

6.4 Margin of Safety

Incorporating a Margin of Safety (MOS) is a required component of TMDL development. The MOS accounts for the uncertainty between pollutant loading and water quality and is intended to ensure that load reductions and allocations are sufficient to sustain conditions that will support beneficial uses. 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 (EPA, 1999). The TMDLs within this document incorporate an implicit MOS in a variety of ways that are discussed in detail by pollutant in **Sections 7-9**.

SECTION 7.0
TEMPERATURE SOURCE ASSESSMENT, LOAD ALLOCATIONS, AND MARGIN OF SAFETY

This section addresses three components of TMDLs associated with reducing the loading of pollutants to surface waters, specifically the source assessment, load allocations, and margin of safety. These interrelated elements provide the quantitative basis for reducing pollutants and meeting water quality standards, while addressing uncertainty.

A comprehensive source assessment is a critical component of water quality restoration planning and a required element of TMDL plans. The objective of the source assessment is to characterize the type, magnitude, and location of pollutant sources to surface waters. The first step in accomplishing this aim is a compilation of an inventory of all possible sources (EPA 1999). Procedures to achieve this vary with pollutant and stream; however, a number of general approaches apply. These include assessments of maps, reports, or field surveys. Because of the complexity of source loading and watershed delivery processes across basins, a combination of techniques is typically necessary.

Following source inventory, the next step is determination of the relative magnitude of loading from various sources with emphasis on the primary and controllable sources. Natural sources of a pollutant are also a consideration, although reduction of pollutant loading from these sources is not a goal. Modeling, statistical analyses, literature review, or a combination of methods facilitates estimating of the magnitude of pollutant loading from the identified sources.

With identification of sources and their relative contributions determined, the next step in the TMDL process is to allocate an allowable load to each of the identified sources. A load allocation is the component of the TMDL plan that assigns an overall load, or reduction in pollutant loading, for each source and is a required element of a TMDL plan. A TMDL is the sum of waste load allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources (**Equation 7-1**). In addition, the TMDL includes a margin of safety (MOS) that accounts for the uncertainty in the relationship between pollutant loads and the quality of the receiving stream.

Equation 7-1:

$$TMDL = \Sigma WLA + \Sigma LA + MOS$$

Monitoring, modeling, and extrapolation has provided much of the technical framework for developing allocations for pollutants across the basin. A brief review of modeling methods, results, and limitations are provided in this document, but details are provided in the technical appendices. Summaries of findings are provided for each pollutant and stream TMDL combination within the document. Allocations are provided to help prioritize restoration activities within the watershed and leverage future funding for restoration.

7.1 Thermal Alterations

In addition to TMDL guidance provided in **Section 7.0**, the Federal Code (40 CFR 130.7c2) provides additional guidance on developing temperature TMDLs and justification for incorporating flow volumes into TMDL planning efforts for temperature. Specifically, the Federal Code prescribes states to estimate the total maximum daily thermal load which cannot be exceeded in order to assure protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife. Pertinent factors in these estimates include water temperatures, flow rates, seasonal variations, existing sources of heat input, and the dissipative capacity of the identified waters.

Thermal alterations are among the listed pollutants of concern for two streams in the Upper Big Hole River TPA, the Big Hole River, and Pintlar Creek. A temperature TMDL for the Big Hole River will be provided in this section of the document. Pintlar Creek's thermal impairment condition is not obvious when assessing existing information, and the main source of thermal influence were irrigation withdrawals. Pintlar Creek Watershed's irrigation system is poorly understood at this time. Therefore, Pintlar Creek's thermal TMDL will be pursued at a later date.

There are no known point sources contributing to thermal loading in the watershed. Nonpoint source (NPS) thermal loading presents a scenario that differs from most pollutants because the "sources" are not heat sources in the true sense. Rather, alterations to riparian vegetation, channel geometry, and flow volumes lead to increased insolation of the water and decreased thermal inertia. These factors ultimately promote warmer or cooler water temperatures by influencing thermal transfer from the surrounding environment to the stream. As detailed in the existing conditions (**Section 5**), these alterations are pronounced along much of the Upper Big Hole River. Because of their role in influencing temperature regime and thermal loading, these "sources" will be referred to as influential factors.

Irrigation return flows, either surface returns via field runoff or from ditches, present another potential source of thermal loading to streams in the Upper Big Hole River TPA. Although these may be relatively discrete inputs, the ephemeral nature of these sources made them difficult to evaluate with available resources. Additionally, given the extent and severity of shrub removal, channel alterations, and dewatering, these sources are likely a minor component of heat entering the Big Hole River. A long-term monitoring and adaptive management approach includes provisions to evaluate irrigation returns and potentially mitigate their inputs.

Several investigations were used to identify and quantify thermal influences and link them to temperature conditions. An aerial photo analysis combined with field investigations identified reaches where modifications to riparian vegetation, channel geometry, and flow modification possibly impact temperatures. Continuous temperature monitoring devices were deployed along with stream channel, riparian vegetation, stream shading, and discharge field measurements. Thermal modeling was built upon temperature, stream flow, and riparian vegetation monitoring results, and modeling results provide the basis to allocate among influential thermal factors in the Big Hole. The influential factors investigated to determine their role in attenuating thermal loading included riparian vegetation, channel geometry, and flow volume.

7.1.1 Source Assessment

Aerial photo evaluations indicated reduced shrub cover was considerable along the Big Hole River with nearly one-third the length having sparse riparian vegetation (Confluence et al. 2003). These results indicate lack of shading is a significant potential factor influencing thermal loading on the Big Hole River. The expected riparian vegetation community is shrub dominated in this area. Sparse riparian conditions covering about one-third of the Upper Big Hole River segment, moderate conditions cover 44%, and dense riparian conditions covering about a quarter of the segment. Similarly, evidence of bank erosion visible in aerial photos provides a means to evaluate lateral channel adjustments which are usually associated with channel widening. Reaches with obvious evidence of bank erosion comprised over 33% of the entire length of the Big Hole River. Moreover, comparisons among vintages of aerial photos allowed calculation of bank migration, with some bend ways moving over 15 feet per year.

Six reaches on the Big Hole River were the subjects of thermal monitoring efforts, and four reaches were modeled using the SSTEMP model (**Table 7-1**). Modeling was used to provide a link between thermally influencing factors and instream temperatures. Two of the reaches were not modeled because of naturally braded stream channel conditions that could not be modeled easily. The studied reaches represented both least impacted and highly impacted reaches. All reaches lie within valley areas with an expected dominant shrub understory. Reference reaches provided the "potential" or least impacted channel dimensions and riparian shading characteristics for use in developing allocations (**Appendix C**). Also, the whole length of the Upper Big Hole River to the confluence of Pintlar Creek was modeled using averaged conditions along the entire reach to estimate overall effects of influencing conditions along the entire segment of the Upper Big Hole River (**Appendix D**).

Table 7-1: Reaches included in thermal modeling efforts for the Upper Big Hole River TPA.

Stream	Reach	Reference or Impacted	Monitored	Modeled
Big Hole River	BH09	Reference	Yes	No
Big Hole River	BH18	Reference	Yes	Yes
Big Hole River	BH19	Impacted	Yes	No
Big Hole River	BH22	Impacted	Yes	Yes
Big Hole River	BH26	Impacted	Yes	Yes
Big Hole River	BH28	Reference	Yes	Yes
Big Hole River	All	Both	See above	Yes

The stream segment temperature model or SSTEMP (Bartholow 2002) evaluates the thermal effects of proposed management strategies. The modeling is completed by first calibrating the model and then altering riparian vegetation, the physical characteristics of the stream, or altering stream withdrawals on individual stream segments. SSTEMP is a simplified version of the stream network temperature model (SNTEMP) designed to develop temperature models for large stream systems or networks (Bartholow 2002). SSTEMP is a physically based model that operates on basic energy balance principles. Data inputs include hydrology, meteorology, stream channel geometry, time of year, and shading (topographic and vegetative). SSTEMP includes a sensitivity and uncertainty analysis feature, which allows the modeler to see which input parameters have the greatest effect on the predicted output. The model gives predictions of mean daily and maximum water temperatures at the downstream end of the modeled reach.

Because of the reasoning reported in **Appendix B**, the model generally didn't calibrate with high certainty for the study reaches. An alternative was the development of a demonstrative model design using flow, temperature, and meteorological data available from the summer of 2004. This alternative was feasible given the relatively small data collection budget and the complex stream channel and irrigation systems in the study areas. Because it has not been fully calibrated, the drawback of the SSTEMP modeling effort is that it cannot be used to predict resultant temperatures over a wide range of hydrologic and meteorological conditions for the segments that were modeled. However, a semi-calibrated model can be used to provide comparisons of the relative significance of altered flow rate, riparian vegetation, and channel geometry on thermal loading and reach outflow temperatures.

Weather is the biggest driving force of temperature within the Upper Big Hole River, but was held constant for warm summer conditions during modeling. Modeling results indicate that summertime temperatures within the Upper Big Hole River is related to the three major human caused influential factors, riparian shading, stream flow, and channel geometry, in different ways. Based on analysis of *mean* daily outflow results of the SSTEMP models, the most significant factor influencing thermal pollution to the Upper Big Hole River is reduced riparian vegetation, followed by impacts from reduced stream flow and over-widened channel geometry (in decreasing order of significance). Based on analysis of *maximum* daily outflow results of the SSTEMP models, the most significant source of thermal influence to the Upper Big Hole River is reduced stream flow, followed closely by reduced riparian vegetation and over-widened channel geometry (**Appendix B**).

The model provides estimated temperature reductions which would come from implementing reasonable irrigation management practices, regenerated riparian shrubs, and restoring channel conditions. Almost all of the impacts influencing these conditions are resulting from agricultural practices. The modeling effort identifies that existing temperature conditions in the Upper Big Hole River exceed the applicable temperature water quality standard.

7.1.2 Temperature TMDL and Load Allocations

Monitoring and modeling results provide the technical framework for developing a surrogate based temperature TMDL and allocation approach within this document (**Appendix B**). If this surrogate based TMDL approach is employed, the thermal loading capacities provided in **Appendix B** will be met. Although a daily and instantaneous thermal loading capacity for heat is provided in **Appendix E**, they are not especially functional for restoration guidance. A surrogate-based TMDL approach provides utility in restoration efforts and is a sensible approach in this watershed because there are no point sources. The thermal loading capacities provided in **Appendix D** and the surrogate based approach, if implemented, will result in thermal loading reduction and assimilative capacity necessary to meet Montana's temperature standard applicable to the Big Hole River (**Section 3**). The surrogates for thermal loading are:

- The percent change in riparian canopy cover over the river that will achieve reference potential, applied to the sources that are currently limiting shade.
    - *Human Influences:* Almost all of the impact to riparian canopy cover is due to present or historic agricultural activities.
    - *Link to thermal conditions*:
        - More shading reduces sunlight, and thus heat, entering the stream.
        - Riparian vegetation creates a microclimate that is cooler than the surrounding landscape.
- Percent reduction in bankfull width to depth ratio of the Upper Big Hole River channel geometry.
    - *Human Influences*: Almost all of the impact to riparian canopy cover is due to present or historic agricultural activities.
    - *Link to thermal conditions*:
        - Lower width to depth ratio means a deeper, narrower channel that has small contact area with warm afternoon air.
        - Lower width to depth ratio will increase the effectiveness of shading produced by the riparian canopy.
- Reduction in warm water irrigation return flows via adaptive management approach.
    - *Human Influences*: Return flows may result from the agricultural irrigation system.
    - *Link to thermal conditions*:
        - Increased thermal load
- Increase instream flow volume due to voluntary reasonable irrigation water management practices and water leasing system that fit into existing water right framework. (This is not an allocation because it is not a true source of heat, but it influences the streams ability to buffer extreme temperature conditions.)
    - *Human Influences*: Agricultural activities.
    - *Link to thermal conditions*:
        - Increased water volume can attenuate a given thermal load to a lower temperature than a lesser volume of water.
        - More water in the stream channel decreases the surface area to water volume ratio. A decreased surface to volume ratio decreases the attenuation capacity of the stream.

Thermal conditions within the Big Hole River are largely the result of complex interactions among the factors outlined above, which prevents an easy interpretation of the influence of each one separate from the others. Modeling results indicate that all of these factors are affecting temperature in the Upper Big Hole River. **Table 7-2** provides a surrogate load allocation approach. The allocations indicate the relative change needed for each temperature influencing factor. If allocations are met in combination, they will achieve Montana's temperature standards. All thermal load reductions from the surrogate TMDL approach are allocated to agricultural activities and can be achieved by applying reasonable land, soil, and water conservation practices. The allocation approach was built upon reference conditions within the watershed where conservation practices are in use but the land is supporting agricultural activities. Daily and instantaneous thermal loading capacity (kilocalories/time) are provided in **Appendix D**.

Table 7-2: Temperature TMDL and allocations for the Upper Big Hole River.

Temperature Surrogates	**Stream**	**Targets and Existing Conditions**	**Load Allocations - The thermal load reduction associated with:**
Thermal Load Surrogates			
Canopy Density Measured Over the Stream	Big Hole River	Increase the median canopy density measured over the stream from 14% to ≥ 43	121% increase in canopy density
	Tributary Streams on the Big Hole River Valley Bottom	Increase the median canopy density measured over the stream from 49% to ≥ 63%	28% increase in canopy density
	Tributary Streams in Mountains	No decrease in canopy density unless conifer encroachment is proven	No change
Width-to-depth ratio	Big Hole River	Decrease the median W/D ratio from 34 to ≤ 22	35% decrease in width-to-depth
	Tributary streams in the Big Hole River Valley Bottom	Decrease the median W/D ratio from 15 to ≤ 14	6% decrease in width-to-depth
	Tributary Streams in Mountains	No human caused increases in W/D ratio	No change
Irrigation Return Flows	Big Hole River and Tributaries	Unknown but likely a minor source. Address in adaptive management	If present, reduce warm water irrigation return flows by 50%
Assimilative Capacity Surrogates follow (not a target):			
In-stream Flow	Big Hole River and Tributaries	Stream flows are often below the target of 60 cfs and the minimum survival flow of 20 cfs at Wisdom.	All reasonable irrigation water management practices with water savings applied to in-stream flow via a local, voluntary approach.

The allocation strategy and subsequent proposed restoration approaches consider that water rights can not be legally affected by any decisions provided in this document. Therefore, a locally coordinated approach is essential for achieving the goal of increasing summer time instream flows. Increasing thermal assimilative capacity via instream flow conservation must be accomplished within the sovereignty of Montana's water rights law.

7.1.3 Margin of Safety and Seasonal Considerations

Montana's temperature standard indicates there can be either a 0.5°F or 1°F increase in temperature above naturally occurring temperatures depending upon what the magnitude of the naturally occurring temperature. The margin of safety considerations for the thermal surrogate TMDL apply an implicit safety factor because if they are fully achieved, would reduce temperatures to naturally occurring levels without the standards consideration of 0.5°F or 1°F heating above naturally occurring temperatures.

Allocations to riparian shading incorporate data from a least impacted reach on the Big Hole River that had exemplary riparian conditions, in conjunction with well-managed livestock grazing. Similarly, desired channel geometry follows a conservative approach based on three reference reaches showing stable channel geomorphology and width-to-depth ratios considerably lower than impaired reaches. Another provision to ensure margin of safety involves assessing not only the factors that affect thermal loads, but also addressing in-stream flows that affect the streams capacity to absorb heat without increasing temperature.

Seasonal considerations are significant for temperature. Obviously, with high temperatures being a primary limiting factor for Arctic grayling in the Big Hole River, summer temperatures are a paramount concern. Therefore, focusing on summer thermal regime is the appropriate approach. Nevertheless, the types of perturbations in the Upper Big Hole River TPA may also limit overwintering habitat. Removal of canopy cover increases formation of anchor ice, ice jams and bank scour from ice, which may physically limit habitat for fish (Winegar 1977). This may be especially pronounced in overly wide sections where conditions for anchor ice formation are favorable. Therefore, although the allocations and restoration plans were developed chiefly with summer temperatures in mind, the aquatic community will also benefit during winter months because the restoration approaches will likely decrease extreme temperature fluctuations. In portions of the Big Hole River, anchor ice and ice scour conditions will likely be abated.

7.1.4 Uncertainty and Adaptive Management

The source assessments used as the basis for the percent reduction allocations to influencing factors assessed all sizeable thermal sources. Uncertainty in the linkage of influencing factors to thermal loading is addressed through an adaptive management approach where the TMDL and allocations from this document can be revised as additional information is collected. Adaptive management is part of the MOS and requires long-term monitoring to track BMPs and stream conditions to determine if targets have been achieved. This approach allows management recommendations and practices to be revised if targets have not been met. Monitoring recommendations are detailed in **Section 11.0.**

The loads and allocations established in this document are meant to apply to recent conditions of natural background and natural disturbance. Under some periodic but extreme natural conditions, it may not be possible to satisfy all targets, loads, and allocations because of natural short term affects to temperature. The goal is to ensure that management activities are undertaken to achieve loading approximate to the TMDLs within a reasonable time frame and to prevent significant longer term excess loading during recovery from significant natural events.

Noticeable improvement in habitat and reduction in sediment loading will not occur until most types of restoration mechanisms or management based activities have been in place for several years or more. Habitat improvements, due to grazing BMPs should be observable within 5-10 years after project implementation. Therefore, thermal reductions from the allocation process will be a long-term goal.

Any influencing factors that increase water temperatures, including global warming, could impact thermally sensitive fish species in Montana. The assessments and technical analysis for the temperature TMDLs considered a worst case scenario reflective of current weather conditions, which inherently accounts for any global warming to date. Allocations to future changes in global climate are outside the scope of this project but could be considered during the adaptive management process if necessary.

SECTION 8.0
SEDIMENT SOURCE ASSESSMENT, LOAD ALLOCATIONS, AND MARGIN OF SAFETY

TMDLs and load allocations will be developed for the streams in need of sediment TMDLs (**Section 5.0**). A TMDL is a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards. More specifically, a TMDL is the sum of waste load allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources and natural background sources. In addition, the TMDL includes a margin of safety (MOS) that accounts for the uncertainty in the relationship between pollutant loads and the quality of the receiving stream. The allowable pollutant load must ensure that the water body being addressed by the TMDL will be able to attain and maintain water quality standards regardless of seasonal variations in water quality conditions, streamflows, and pollutant loading. Because there are no point sources within the Upper and North Fork Big Hole River TPA, WLAs are excluded and TMDLs are expressed by the following equation:

$$\text{TMDL} = \Sigma\text{LA} + \text{MOS}$$

The sediment TMDL process presented in this main document for the TPA will adhere to this TMDL loading function, but use an average annual sediment yield source assessment, a percent reduction in loading allocated among sources, and an inherent margin of safety. A percent reduction approach is used because there is uncertainty associated with the loads derived from the source assessment, and using the estimated sediment loads creates a rigid perception that the loads are absolutely conclusive. A percent reduction allocation also considers the whole watershed as a source area and fits into a watershed wide water quality restoration planning approach. The total maximum daily load for each 303(d) listed water body is expressed as an overall percent reduction in the sediment load and is derived from the sum of the percent reduction allocations to varying sources.

Because there are no point sources and sediment generally has a cumulative effect on beneficial uses, an annual expression of the TMDLs was determined as the most appropriate timescale to facilitate TMDL implementation. EPA encourages TMDLs to be expressed in the most applicable timescale but also requires TMDLs to be presented as daily loads (Grumbles 2006); daily loads are provided in **Appendix F**.

8.1 Allocation Development

The percent reduction allocations are based on the modeled BMP scenarios for each major source type (i.e. unpaved roads, upland erosion, and streambank erosion) and reflect reasonable reductions as determined from literature, agency and industry documentation of BMP effectiveness, and field assessments of areas with reasonable conservation practices in place. Percent reductions are expected to be achieved through a combination of BMPs, and the most appropriate BMPs will vary by site. **Section 8.2** provides a brief review of sediment source assessment techniques. No point sources are located in the watershed and all wasteload allocations are zero.

8.2 Sediment Source Assessment Summary

Sediment is among the pollutants of concern for a majority of the listed streams in the Upper and North Fork Big Hole River planning area (**Table 8-1**). The current ability to quantify sediment loads from diffuse sources across a large landscape such as those found within the Big Hole Watershed provides relative sediment estimates rather than exact sediment yields. An inventory of sediment sources began with a field reconnaissance, and an aerial photo survey completed in the first phase of TMDL planning (Confluence et al. 2003). In conjunction with the existing stream condition surveys, specific sediment source assessment activities consisted of eroding bank surveys, evaluations of riparian community structure and assessment of human activities that influence bank erosion. Sediment derived from bank erosion was estimated along each reach that was monitored and extrapolated across the watershed. Road surveys and associated road runoff modeling evaluated potential inputs from road crossings. The Montana Department of Transportation evaluated contributions of sediment to streams from road traction sanding on highway 43 (Hydrometrics 2005). Finally, watershed scale modeling efforts allowed estimation of anthropogenic upland erosion sources of sediment and their relative contributions to streams across the basin.

Table 8-1: Sediment TMDLs provided in the Upper/North Fork Big Hole TPAs

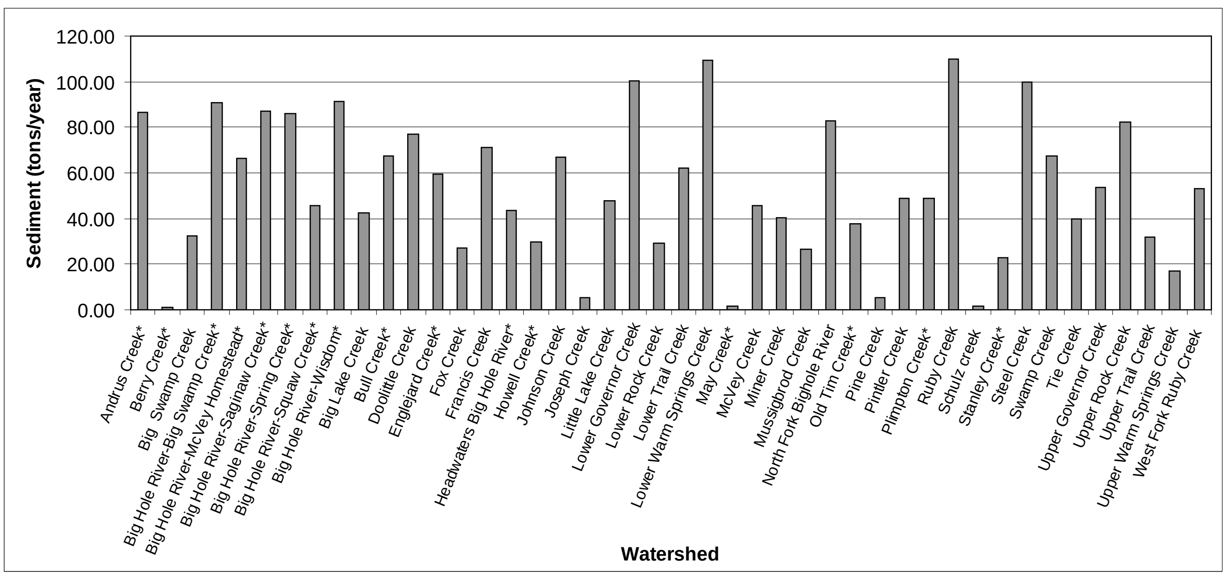
Big Hole River	North Fork Big Hole River
Doolittle Creek	Pine Creek
Fox Creek	Rock Creek
Francis Creek	Ruby Creek
Governor Creek	Schultz Creek
Johnson Creek	Steel Creek
Joseph Creek	Swamp Creek
McVey Creek	Tie Creek
Miner Creek	Trail Creek
Mussigbrod Creek	

8.2.1 Road Sediment Modeling

Fine sediment contributed from roads is a common source of sediment loading to streams. Factors relating to the potential for roads to contribute sediment to streams include road surface materials, proximity to streams, local topography, potential for conveyance, local road prism geometry, and cut/fill slope and vegetation cover. Application of the Washington road surface erosion model (WARSEM) allowed estimation of existing sediment loading from roads and potential reductions in loadings with implementation of road BMPs. The model is a Microsoft Access based model developed for and used by the State of Washington Department of Natural Resources for assessing sediment production and delivery to streams from roads under its jurisdiction. WARSEM is an empirical model, and estimates sediment production and delivery based on road surfacing, road use, underlying geology, precipitation, road age, road gradient, road geometry (including road configuration and ditch geometry), cut slope cover, and other factors (Dube et al. 2004).

To extrapolate the unpaved road runoff model results from the sampled road segments to the watershed as a whole, comprehensive datasets representing the locations of roads and streams were necessary. The GIS coverage of 2000 US Census Bureau's Topologically Intergrated Geographic Encoding and Referencing system (TIGER) road data for road locations, and the National Hydrography Dataset (NHD) for stream locations provided the basis for this extrapolation. Digitization of additional road locations from 1:24,000 scale digital orthophotos supplemented the coverage of local roads in the TIGER data. Sample sites were randomly picked from the road database and sampled. Site data was used for Washington Road Surface Erosion Model (WARSEM) modeling and ultimately the WARSEM results were extrapolated to the watershed scale using the initial GIS maps as the basis (**Appendix G**). Extrapolation to the entire watershed was based on three parameters, the lumped road class, road/stream orientation, and geology erosion factor.

Roads contribute variable sediment loads depending upon the local road network (**Figure 8.1**). The unpaved road runoff model indicates that various restoration approaches will provide considerable reduction in sediment loading to the watershed's stream network. The effectiveness of various BMPs, in terms of the amount of estimated reduction in sediment delivery, varies by sub-watershed. Reducing contributing road lengths that drain to streams along with roadside ditch BMPs will reduce loading significantly for most watersheds (**Appendix X**).



*watersheds with asterisks do not coincide with 303d listed tributaries but contribute to the overall load contributed to the upper Big Hole River segment. Some 303d listed watersheds may be broken into two reporting areas within this figure.

Figure 8-1: Sediment contribution from roads within watersheds in the upper Big Hole TPA.

8.2.2 Road Traction Sanding

Application of sand to highways during winter months has the potential to increase loading of fine sediment (< 2 mm in diameter) to surface waters in the Upper and North Fork Big Hole River planning area. Source assessments for this category of fine sediment delivery included spatial evaluations of roads adjacent to streams, and a study commissioned by the Montana Department of Transportation (MDT) to evaluate contributions to select streams in the basin (Hydrometrics 2005). Essentially, this study provides many components of the TMDL with respect to this potential source of fine sediment. This includes a source assessment, evaluation of the relative contribution, and a basis to allocate an allowable load from this source.

Field reconnaissance investigations indicated stream crossings and stream adjacent reaches of highway where the features associated with potential delivery of road traction sand to surface waters (Hydrometrics 2005). Sand entered highway adjacent reaches after being thrown or washed down embankments; however, presence of a flat, vegetated drainage bottom between the embankment and stream impeded most of the delivery to streams. Observers identified ten reaches presenting a sediment delivery risk (**Table 8-2**) and rated these according to their relative potential based on performance on a questionnaire that evaluated distance from road to stream, percent vegetative cover, slope of the embankment, observed presence of sand, and evidence of conveyance.

Table 8-2: Field reconnaissance results for Trail Creek stream segments proximal to Highway 43 (Hydrometrics 2005).

Stream Reach ID	Relative Road Sand Loading Potential (field inspection score)*	Stream Length Adjacent to Road Embankment	Average Distance Road Shoulder to Stream
TC-1	Low (10.0)	250	20
TC-2	Low (9.5)	300	30
TC-3	High (14.0)	300	15
TC-4	Low (9.0)	150	20
TC-5	High (12.5)	100	25
TC-6	High (12.5)	100	20
TC-7	High (12.5)	40	30
TC-8	Medium (12.0)	100	30
TC-9	Medium (12.0)	100	20
TC-10	Medium (12.0)	700	25

* Relative road sanding loading potential based on GIS analysis and field reconnaissance. Ratings are relative.

Stream crossings also presented risks for sediment loading along Highway 43 with 11 crossings identified as having moderate to high loading potential (**Table 8-3**). Factors contributing to delivery potential included distance of road to the stream, vegetative cover between road and stream, presence of road sand, and evidence of delivery of road sand to the stream. Road sand was attributable for a sharp contrast in substrate composition at several crossings. Sand comprised a majority of observed size fractions at these locations.

Table 8-3: Stream crossings with identified potential to deliver traction sand to surface waters in the Trail Creek drainage (Hydrometrics 2005).

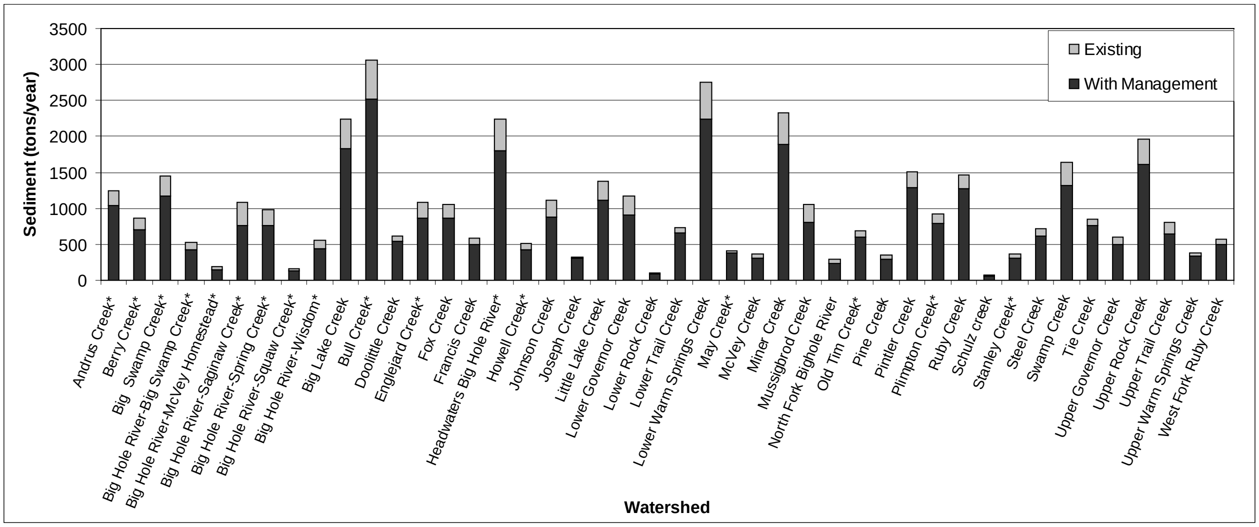
Site	Stream Name	Crossing Type	Relative Loading Potential
TCX-1	Trail Creek	Bridge	High
TCX-2	Sheep Creek	Culvert	Moderate
TCX-3	Trail Creek	Bridge	High
TCX-4	May Creek	Culvert	Moderate
TCX-5	Trail Creek	Bridge	High
TCX-6	Canyon Creek	Culvert	Moderate
TCX-7	Cascade Creek	Culvert	Moderate
TCX-8	Sage Creek	Culvert	Moderate
TCX-9	Runaway Creek	Culvert	Moderate
TCX-10	Placer Creek	Culvert	Moderate
TCX-11	Trail Creek	Bridge	High

* Relative loading potential based on GIS analysis and field reconnaissance.

The Hydrometrics study (2005) also assessed loads from the different source areas. Roadside embankments delivered 0.54 tons of sand to streams, and delivery at road crossings totaled 0.90 tons of sand, for 1.44 tons/year in the 2004-2005 winter season. Although road traction sanding and fill erosion are a small proportion of the overall sediment load for any 303d listed stream, allocations are provided. The allocation for road traction sand and any erosion from road prism fill is a 10 percent reduction. This reduction is based on the likelihood that BMP performances of restoration activities provided in the restoration section of this document will achieve at least a 10 percent reduction from road sanding and maintenance.

8.2.3 Upland Erosion

An upland erosion analysis using the universal soil loss equation estimates that hillslope erosion contributes approximately 43,000 tons of sediment per year to streams in the Upper and North Fork Big Hole River Watersheds (**Figure 8-2**). About 18 percent of upland erosion is attributable to human caused sources that can be reduced through the application of soil conservation practices. Similar to the relative amount of land use types found in the watershed, agriculture land and forest areas are the predominant sources of soil erosion within the Upper Big Hole Watershed. Timber harvest has the potential for transient short term (3-5 years) increases in sediment loading if located near streams. Yet the source assessment and allocation approach is valid because timber harvest is anticipated to occur at some level over time. As timber harvest areas reach 3-5 years in age, new areas will likely be harvested. Agricultural activities such as grazing and hay production provide sediment loads year after year in constant locations although hay production may produce higher short term loads when reseeded or rotated to alfalfa. **Appendix A** provides a review of the hillslope erosion rates by land cover type for all 6th code HUC watersheds in the basin. Agricultural practices that increase groundcover within the watershed have the most potential to reduce landscape erosion. Results of modeling agricultural practices that increase upland cover will be used to build sediment TMDLs and allocations, although increasing riparian vegetation's filtering capacity along the watersheds stream network is also an approach that will reduce sediment yield from upland sources (**Appendix A**).



*watersheds with asterisks do not coincide with 303d listed tributaries but contribute to the overall load to the upper Big Hole River segment. Some 303d listed watersheds may be broken into multiple watershed areas within this figure.

Figure 8-2: Estimated upland sediment load from watersheds within the Upper Big Hole TPA.

8.2.4 Sediment Contributed from Eroding Banks

Streambank erosion is an inherent part of channel evolution and contributes sediment to stream systems in response to a combination of climatic and physiographic factors. However, anthropogenic impacts, including poor land management, road systems, riparian vegetation removal, and/or channel alterations can result in elevated rates of streambank erosion and subsequent impacts to beneficial uses.

Sediment loading from streambank erosion was assessed in the upper Big Hole TPA by performing BEHI measurements and evaluating the Near Bank Stress (NBS) (Rosgen and Silvey 1996; Rosgen 2001). Measurements were made at 52 reaches along the Big Hole River and listed tributaries (**Appendix H**). BEHI scores were determined at each visually eroding streambank based on the following parameters: bank height, bankfull height, root depth, root density, bank angle, and surface protection. In addition to BEHI data collection, surrounding land use practices and adjacent streamside vegetation condition were recorded. BEHI scores and estimates of sheer stress were used to estimate bank retreat rates using comparisons to regional bank retreat studies (**Appendix H**). Bank retreat rates, area of eroding bank, and bulk soil densities were used to estimate annual sediment load from monitored reaches.

Sediment loads from the reach scale were extrapolated to the watershed scale using aerial photos and GIS tools as described in **Appendix H**. Because riparian vegetation is crucial for bank stabilization, the existing and potential vegetation type and density were determined for all reaches. Average erosion rates associated with each reach type (based on land use and vegetation) were used to extrapolate bank erosion to each subwatershed within the TPA. To estimate the sediment reductions that could be achieved by the application of riparian BMPs, the loading rate was calculated for the potential vegetation type and density of each reach type when BMPs are in place. A more detailed description of this assessment can be found in *Sediment Contribution from Streambank Erosion*, which is included as **Appendix H**.

Bank erosion monitoring and modeling results indicate substantial reductions in sediment loading from eroding banks is possible with the recovery of riparian vegetative cover. Restoring riparian cover will result in an average 31 percent reduction of sediment loading from this source at a basin scale, or a reduction estimated at approximately 35,000 tons per year to the basin's streams (**Table 8-4**). Expressing this sediment load allocation by sub-watershed allows for prioritization of the largest contributors of sediment. Most human caused bank erosion in the Upper Big Hole Valley is caused by grazing and other agricultural activities, followed by road encroachment and road crossings.

Table 8-4: Bank erosion assessment results and allocations for sub-watersheds in the upper Big Hole River planning area.

6th Code HUC WS (Mod for 303d)	Length of Streams in WS (ft)	Estimated Current Sediment Delivery (ton/yr)	Estimated Potential Sediment Delivery (ton/yr) Allocation by Sub-watershed	Percent Reduction
Andrus Creek*	158,037	3,106	1,411	55%
Berry Creek*	63,938	115	115	0%
Big Swamp Creek	160,963	1,175	644	45%
Big Hole River-Big Swamp Creek*	219,221	4,645	2,034	56%
Big Hole River-McVey Homestead*	206,932	3,647	3,101	15%
Big Hole River-Saginaw Creek*	164,496	2,972	1,461	51%
Big Hole River-Spring Creek*	221,595	3,563	2,592	27%
Big Hole River-Squaw Creek*	88,626	1,252	902	28%
Big Hole River-Wisdom*	278,607	6,012	3,166	47%
Big Lake Creek	279,616	5,167	2,373	54%
Bull Creek*	248,229	4,534	2,569	43%
Doolittle Creek	104,967	596	360	40%
Englejard Creek*	166,425	1,392	953	32%
Fox Creek	95,167	1,671	745	55%
Francis Creek	139,896	1,625	1,203	26%
Headwaters Big Hole River*	150,887	909	741	19%
Howell Creek*	137,297	1,864	850	54%
Johnson Creek	166,451	1,135	810	29%
Joseph Creek	89,420	662	469	29%

Table 8-4: Bank erosion assessment results and allocations for sub-watersheds in the upper Big Hole River planning area.

6th Code HUC WS (Mod for 303d)	Length of Streams in WS (ft)	Estimated Current Sediment Delivery (ton/yr)	Estimated Potential Sediment Delivery (ton/yr) Allocation by Sub-watershed	Percent Reduction
Little Lake Creek	155,528	1,525	1,013	34%
Lower Governor Creek	237,202	5,645	2,735	52%
Lower Rock Creek	91,825	2,500	1,766	29%
Lower Trail Creek	178,277	772	759	2%
Lower Warm Springs Creek	273,215	4,306	2,852	34%
May Creek*****	110,953	409	409	0%
McVey Creek	101,633	1,339	866	35%
Miner Creek	173,301	1,326	1,152	13%
Mussigbrod Creek	153,143	1,058	857	19%
North Fork Big Hole River	348,852	5,039	3,843	24%
Old Tim Creek*****	109,531	1,581	1,198	24%
Pine Creek	40,745	604	227	62%
Pintlar Creek	160,145	1,222	1,140	7%
Plimpton Creek*****	277,692	3,225	2,307	28%
Ruby Creek	238,309	1,715	1,598	7%
Schulz creek	17,672	32	32	0%
Stanley Creek*****	131,206	2,844	1,674	41%
Steel Creek	164,910	1,755	910	48%
Swamp Creek	281,630	4,123	2,889	30%
Tie Creek	194,539	876	656	25%
Upper Governor Creek	133,856	2,251	1,112	51%
Upper Rock Creek	164,268	2,409	1,366	43%
Upper Trail Creek	174,824	1,283	970	24%
Upper Warm Springs Creek	121,202	1,460	1,133	22%
West Fork Ruby Creek	137,982	878	832	5%
Total/Average Percent Reduction	7,313,208	96,218	60,796	31%

***** watersheds from the table above do not apply to a specific 303d listed tributary, but cumulatively contribute to the Big Hole River's bank erosion load. Some 303d listed watersheds may be broken into multiple reporting areas within this table.

8.2.5 Margin of Safety and Seasonality Considerations Relating to the Sediment Source Assessments

No implicit or explicit margins of safety were included in sediment source assessment modeling. Modeling decisions and assumptions were driven by applicability to the Big Hole rather than artificially conservative estimates. All assessments and models estimate loads on an annual basis. Most of the sediment sources are associated with spring run off or summer thunderstorms result in episodic inputs. Source assessments based on annual load estimates are appropriate because the sediment TMDLs are provided to control siltation and sedimentation on the stream bed, these conditions are influenced during long term timeframes. Daily loads were extrapolated from these average annual source assessments in **Appendix F** in order to meet federal requirements.

8.3 Source Assessment Results, TMDLS and Allocations

The sources of sediment within the upper Big Hole Valley and surrounding mountain ranges that this TMDL planning area include, are generally similar in all of the tributary watersheds. Predominant sources are natural, livestock grazing in riparian areas, livestock grazing in uplands, hay production, unpaved road systems and timber harvest. Very localized impacts may include historic mining practices, urban areas and road sanding practices. Some localized sources that are likely not significant are not addressed in the sediment allocations.

Only a few watersheds have significant silvicultural activity during the past three decades. These include Johnson, Tie, Trail and Ruby watersheds. Many of the timber harvest activities in these areas may have left lingering sediment in the streams but recent large scale harvest has not occurred. Therefore, timber harvest activities are not targeted for reduction based allocations other than to keep sediment yields at or below existing contributions. Unpaved road systems that support recreation, livestock grazing and silvicultural activities in the mountains, foothills and valleys have various impacts on each watershed and allocation approaches differ widely depending on specific conditions within each area.

Historically, timber harvest and large scale fire suppression efforts have occurred. Recently, less fire suppression, a warming trend, biological factors and the lacking ability of the USFS to manage fuels have culminated to provide conditions where fires are influencing large portions of the forested landscape. Overall erosion rates may be lower or equal to natural fire regimes when implementing well managed harvest management and/or prescribed fire in a watershed but spatial and temporal sediment production may be altered by active forest management. Changes in temporal and spatial sediment production likely would affect beneficial uses differently than a natural fire regime. Sediment production from fire is considered in the upland sediment source assessments and attributed to natural loads for the TMDL source assessments.

Bank erosion is a very pervasive source of sediment that is influenced naturally, but also to a significant degree from agricultural practices. This source is usually significant and addressed in all TMDLs sediment reduction allocation approach. Grazing and hay production also have the potential to affect upland erosion rates. In some watersheds these sources are provided an allocation also. The allocation to upland sources may be met by increasing upland vegetation vigor or increasing riparian buffer filtering function by promoting re-growth of streamside vegetation. Mining activities that affect bank erosion are localized and captured within the bank erosion component of the allocation approaches.

The following sections provide sediment source assessment summary TMDLs and annualized percent reduction based sediment allocations in table format. The more preventable and controllable the human caused source, the larger the percent reduction within the allocation approach. Costs are considered in restoration approaches but in the Upper Big Hole Watershed, the two largest controllable sediment contributors are eroding banks and grazing sources, both controllable with fencing and grazing management. Roads also contribute sediment and may be slightly more costly to fix on a cost/benefit basis but well within the definition of reasonable land conservation approaches. Estimated daily sediment load TMDLs are provided in **Appendix F**.

8.3.1 Big Hole River

This segment of Big Hole River originates south of Jackson, Montana in the Beaverhead Mountains and flows northward ending at its confluence with Pintlar Creek (**Appendix K**, **Map 1**). Tributaries flow from the Beaverhead, Pioneer and Pintler mountain ranges. The major tributaries include the North Fork Big Hole River, Warm Spring, Steel, Swamp, Governor, Big Lake, and Rock Creeks. Pine forests dominate upper elevations of the watershed. The Big Hole Valley is a broad, low gradient valley dominated by hay and cattle production.

Unpaved roads in the Upper Segment of the Big Hole River's watershed are estimated to contribute less than 1 percent of the overall sediment yield, yet they may have localized impacts. Most of the sediment produced from bank erosion in this watershed is derived from livestock grazing systems and natural sources. Lessening the grazing impacts to the river and tributary streams corridors should be a priority. Overall, a large portion of riparian corridors within the watershed could benefit from upgrading current grazing management practices for reducing bank erosion and providing better filtering of upland sediment.

The TMDL for this segment of the Big Hole River is a combination of allocations to reduce sediment production from eroding banks via riparian management, increasing riparian filtering of upland sediment loads, a reduction of sediment from roads, and no long term sediment load increase from timber harvest. The overall TMDL is presented as a 31 percent reduction in annual sediment load (**Table 8-5**).

Table 8-5: Sediment Source Assessment, Allocations and TMDL for Upper segment of the Big Hole River

Sediment Sources		Current Estimated Load (Tons/Year)	Sediment LAs
Roads		2344	29% reduction
Eroding Banks		96,218	37% reduction
Upland Sediment Sources	**Silviculture**	459	No modeled increase in sediment delivery to the stream or tributaries
	Grazing/Hay Lands	32,699	23% reduction
	Natural Sources	10,256	NA
Total Sediment Load/TMDL		141,976	31% reduction

* A significant portion of bank erosion and grazing/hay are a natural load.

8.3.2 Doolittle Creek

Doolittle Creek is a tributary of the Big Hole River which flows from the Pioneer Mountains northwest to the confluence with the Big Hole River (**Appendix K**, **Map 1**). The predominant land uses in the watershed are livestock production, including rangeland grazing and irrigated pastures. Also, forest activities such as historic harvest and current forest recreation activities are present.

Unpaved roads in the Doolittle Creek watershed are estimated to contribute 6 percent of the overall sediment yield. A large effort to remedy road erosion from entering the streams in this watershed was undertaken and therefore the watershed wide sediment reduction from the road network is lower than other watersheds. Most of the sediment produced from bank erosion in this watershed is derived from natural sources or historic livestock grazing systems. Banks are healing in many reaches but need more time to recover. A small portion of the stream corridor could benefit from upgrading current grazing management practices for reducing bank erosion and providing better filtering of upland sediment.

The TMDL for Doolittle Creek is a combination of allocations to reduce sediment production from eroding banks via riparian management, increasing riparian filtering of upland sediment loads, a reduction of sediment from roads, and no long term sediment load increase from timber harvest. The overall TMDL is presented as a 26 percent reduction in annual sediment load (**Table 8-6**).

Table 8-6: Sediment Source Assessment, Allocations and TMDL for Doolittle Creek

Sediment Sources		**Current Estimated Load (Tons/Year)**	**Sediment LAs**
Roads		77	19% reduction
Eroding Banks		596	40% reduction
Upland Sediment Sources	**Silviculture**	0	No modeled increase in sediment delivery to the stream or tributaries
	Grazing/Hay Lands	373	22% reduction
	Natural Sources	246	NA
Total Sediment Load/TMDL		1,292	26% reduction

* A significant portion of bank erosion and grazing/hay loads are a natural load

8.3.3 Fox Creek

Fox Creek is a small stream in the southern end of the upper Big Hole River planning area (**Appendix K**, **Map 1**). Its headwaters begin in the Big Hole Divide between Dillon and Jackson on USFS lands. After leaving the forest, it flows through private lands for about ¾ of its length before its confluence with Governor Creek.

Unpaved roads in Fox Creek watershed are estimated to contribute less than 1 percent of the overall sediment yield. Most of the sediment produced from bank erosion in this watershed is derived from natural sources or livestock grazing systems. Sediment from eroding banks is one of the largest contributors of sediment and a large portion of this is derived from livestock grazing, especially on the public lands. Livestock grazing has less of an impact on private lands, but irrigation infrastructures may contribute to localized bank erosion here.

The TMDL for Fox Creek is a combination of allocations to reduce sediment production from eroding banks via riparian management, increasing riparian filtering of upland sediment loads, a reduction of sediment from roads, and no long term modeled sediment load increase from timber harvest. The overall TMDL is presented as a 41 percent reduction in annual sediment load (**Table 8-7**).

Table 8-7: Sediment Source Assessment, Allocations and TMDL for Fox Creek

Sediment Sources		Current Estimated Load (Tons/Year)	Sediment LAs
Roads		27	22% reduction
Eroding Banks		1,671	55% reduction
Upland Sediment Sources	**Silviculture**	0	No modeled increase in sediment delivery to the stream or tributaries
	Grazing/Hay Lands	870	22% reduction
	Natural Sources	191	NA
Total Sediment Load/TMDL		2,759	41% reduction

* A significant portion of bank erosion and grazing /hay loads are a natural load

8.3.4 Francis Creek

Francis Creek drains from the east side of the basin flowing to the northwest before its confluence with Steel Creek. The headwaters originate in USFS lands, but most of its length flows through state or private land. Francis Creek then flows into Steel Creek.

Most of the sediment produced from bank erosion in this watershed is derived from natural sources or livestock grazing systems. Sediment produced from eroding banks is one of the largest contributors of sediment and a large portion of this is derived from livestock grazing. Unpaved roads in Francis Creek watershed are estimated to contribute less than 3 percent of the overall sediment yield. Sediment contributions from past timber harvest is currently estimated at three tenths of one percent of the existing sediment yield.

The TMDL for Francis Creek is a combination of allocations to reduce sediment production from eroding banks via riparian management, increasing riparian filtering of upland sediment loads derived from grazing and hay production, a reduction of sediment from roads, and no long term sediment load increase from timber harvest. The overall TMDL is presented as a 23 percent reduction in annual sediment load (**Table 8-8**).

Table 8-8: Sediment Source Assessment, Allocations and TMDL for Francis Creek

Sediment Sources		Current Estimated Load (Tons/Year)	Sediment LAs
Roads		71	28% reduction
Eroding Banks		1,625	26% reduction
Upland Sediment Source	**Silviculture**	6	No modeled increase in sediment delivery to the stream or tributaries
	Grazing/Hay Lands	391	21% reduction
	Natural Sources	186	NA
Total Sediment Load/TMDL		2,279	23% reduction

* A significant portion of bank erosion and grazing /hay loads are a natural load

8.3.5 Governor Creek

Governor Creek, a tributary of the Big Hole River, lies in the southern end of the upper Big Hole River planning area (**Appendix K**, **Map 1**). Its headwaters originate in the Beaverhead Mountains and flow northward to its confluence with the Big Hole River near Jackson, Montana. About 2 miles of the length of Governor Creek flow through mountainous topography on USFS holdings. The remaining 20 miles occupy a rangeland environment on private land.

Most of the sediment produced from bank erosion in this watershed is derived from natural sources or livestock grazing systems. Sediment produced from eroding banks is one of the largest contributors of sediment and a large portion of this is derived from livestock grazing. Unpaved roads in the Governor Creek watershed are estimated to contribute less than 2 percent of the overall sediment yield. Sediment contributions from past timber harvests is currently a minute fraction of the existing sediment yield.

The TMDL for Governor Creek is a combination of allocations to reduce sediment production from eroding banks via riparian management, increasing riparian filtering of upland sediment loads derived from grazing and hay production, a reduction of sediment from roads, and no long term sediment load increase from timber harvest. The overall TMDL is presented as a 41 percent reduction in annual sediment load (**Table 8-9**).

Table 8-9: Sediment Source Assessment, Allocations and TMDL for Governor Creek

Sediment Sources		Current Estimated Load (Tons/Year)	Sediment LAs
Roads		341	32% reduction
Eroding Banks		17,811	51% reduction
Upland Sediment Sources	**Silviculture**	72	No modeled increase in sediment delivery to the stream or tributaries
	Grazing/Hay Lands	6,528	21% reduction
	Natural Sources	894	NA
Total Sediment Load/TMDL		25,646	41% reduction

* A significant portion of bank erosion and grazing /hay loads are a natural load

8.3.6 Johnson Creek

Johnson Creek lies in the northwest portion of the upper Big Hole River Valley and is a tributary of the North Fork Big Hole River. Its headwaters originate in the Anaconda Pintler range and it flows southward approximately eleven miles to its confluence with North Fork Big Hole River.

Most of the sediment produced from bank erosion in this watershed is derived from natural sources or livestock grazing systems. The USFS grazing allotment (Tie-Johnson) receives light use from cattle, with limited time spent on BDNF due to cattle not preferring to occupy allotment (pers. con. Kevin Greenwood, Range Conservationist, Wisdom RD, BDNF). Sediment produced from eroding banks is one of the largest contributors of sediment and a large portion of this is derived from livestock grazing. Unpaved roads in Johnson Creek watershed are estimated to contribute less than 3 percent of the overall sediment yield. Sediment contributions from past timber harvest is estimated at about 3 percent of the existing sediment yield.

The TMDL for Johnson Creek is a combination of allocations to reduce sediment production from eroding banks via riparian management, increasing riparian filtering of upland sediment loads derived from grazing and hay production, a reduction of sediment from roads, and no long term sediment load increase from timber harvest. The overall TMDL is presented as an 18 percent reduction in annual sediment load (**Table 8-10**).

Table 8-10: Sediment Source Assessment, Allocations and TMDL for Johnson Creek

Sediment Sources		Current Estimated Load (Tons/Year)	Sediment LAs
Roads		69	20% reduction
Eroding Banks		1,167	28% reduction
Upland Sediment Sources	**Silviculture**	68	No modeled increase in sediment delivery to the stream or tributaries
	Grazing/Hay Lands	405	22% reduction
	Natural Sources	723	NA
Total Sediment Load/TMDL		2,432	18% reduction

* A significant portion of bank erosion and grazing /hay loads are a natural load

8.3.7 Joseph Creek

Joseph Creek is a small tributary of Trail Creek lying entirely in montane areas of the upper Big Hole River planning area on the west side of the basin. Most of the sediment produced from bank erosion in this watershed is derived from natural sources or historic livestock grazing systems with a small amount derived from cut off of meanders and straightening of the stream due to highway 43 construction. Sediment produced from eroding banks is the largest contributor of sediment. Unpaved roads, road sanding on highway 43, and past timber harvest in Joseph Creek watershed are estimated to contribute a minute amount of the overall sediment yield.

The TMDL for Joseph Creek is solely to reduce sediment production from eroding banks via continuing the existing grazing management approach. Allocations to other sources include no long term sediment load increase from timber harvest, road sanding or the unpaved road system. The overall TMDL is presented as a 19 percent reduction in annual sediment load (**Table 8-11**).

Table 8-11: Sediment Source Assessment, Allocations and TMDL for Joseph Creek

Sediment Sources		Current Estimated Load (Tons/Year)	Sediment LAs
Unpaved Roads		5	No increase
Hwy 43 Road Sanding		1	No increase
Eroding Banks		662	29% reduction
Upland Sediment Sources	**Silviculture**	6	No modeled increase in sediment delivery to the stream or tributaries
	Grazing/Hay Lands	82	No increase
	Natural Sources	234	NA
Total Sediment Load/TMDL		990	19% reduction

* A significant portion of bank erosion and grazing /hay loads are a natural load

8.3.8 McVey Creek

McVey Creek flows to the northwest joining the Big Hole River towards the northern end of the planning area (**Appendix K**, **Map 1**). Much of this stream flows upon public lands. Its headwaters begin in Forest Service holdings and a sizeable amount of the valley portions of the stream flows through state lands.

Most of the sediment produced from bank erosion in this watershed is derived from natural sources or livestock grazing systems. Sediment produced from eroding banks is the largest contributors of sediment and a large portion of this is derived from livestock grazing. Unpaved roads in McVey Creek watershed are estimated to contribute about 1 percent of the overall sediment yield, yet may have localized impacts. There has been no timber harvest in this watershed during the last three decades.

The TMDL for McVey Creek is a combination of allocations to reduce sediment production from eroding banks via riparian grazing management, increasing riparian filtering of upland sediment loads derived from grazing and hay production, a reduction of sediment from roads, and no long term sediment load increase from timber harvest. The overall sediment TMDL is presented as a 25 percent reduction in annual sediment load (**Table 8-12**).

Table 8-12: Sediment Source Assessment, Allocations and TMDL for McVey Creek

Sediment Sources		Current Estimated Load (Tons/Year)	Sediment LAs
Roads		46	28% reduction
Eroding Banks		1,339	35% reduction
Upland Sediment Sources	**Silviculture**	0	No modeled increase in sediment delivery to the stream or tributaries
	Grazing/Hay Lands	269	22% reduction
	Natural Sources	100	NA
Total Sediment Load/TMDL		1,754	31% reduction

* A significant portion of bank erosion and grazing /hay loads are a natural load

8.3.9 Miner Creek

Miner Creek flows northeast from the west part of the basin before its confluence with the Big Hole River. Over half its length lies on USFS lands with the remainder occurring on private lands in the valley. Sediment produced from eroding banks is a large contributor of sediment but most bank erosion is natural in Miner Creek. Unpaved roads in Miner Creek watershed are estimated to contribute less than 1 percent of the overall sediment yield, yet may have localized impacts. A large portion of the watershed consists of upland grasses for livestock grazing systems or hay fields and sediment produced from these areas are partially influenced by human activities.

The TMDL for Miner Creek is a combination of allocations to reduce sediment production from eroding banks via riparian grazing management from limited reaches of the stream, increasing riparian filtering of upland sediment loads derived from grazing and hay production, a reduction of sediment from roads, and no long term sediment load increase from timber harvest. The overall sediment TMDL is presented as a 17 percent reduction in annual sediment load (**Table 8-13**).

Table 8-13: Sediment Source Assessment, Allocations and TMDL for Miner Creek

Sediment Sources		Current Estimated Load (Tons/Year)	Sediment LAs
Roads		40	25% reduction
Eroding Banks		1,326	13% reduction
Upland Sediment Sources	**Silviculture**	0	No modeled increase in sediment delivery to the stream or tributaries
	Grazing/Hay Lands	2,062	21% reduction
	Natural Sources	270	NA
Total Sediment Load/TMDL		3,698	17% reduction

* A significant portion of bank erosion and grazing /hay loads are a natural load

8.3.10 Mussigbrod Creek

Mussigbrod Creek is a tributary of the North Fork Big Hole River lying on the west side of the upper Big Hole River planning area. The stream flows through Mussigbrod Lake near its headwaters. It originates in the Anaconda Pintler Mountain Range and flows for about 8 miles through a montane setting, then through the Upper Big Hole Valley until its confluence with the North Fork Big Hole River. Montana DEQ has included the upper watershed in a water quality reference data gathering project. Most of the impacts to sediment production are in the lower three or four miles of the watershed.

Most of the sediment produced from bank erosion in this watershed is derived from natural sources or livestock grazing systems. Unpaved roads in Mussigbrod Creek watershed are estimated to contribute about 1 percent of the overall sediment yield, yet may have localized impacts. A large portion of the watershed consists of upland grasses for livestock grazing systems or hay fields and sediment produced from these areas are partially influenced by human activities.

The TMDL for Mussigbrod Creek is a combination of allocations to reduce sediment production from eroding banks via riparian grazing management from limited reaches of the stream, increasing riparian filtering of upland sediment loads derived from grazing and hay production, a reduction of sediment from roads, and no long term sediment load increase from timber harvest. The overall sediment TMDL is presented as a 14 percent reduction in annual sediment load (**Table 8-14**).

Table 8-14: Sediment Source Assessment, Allocations and TMDL for Mussigbrod Creek

Sediment Sources		**Current Estimated Load (Tons/Year)**	**Sediment LAs**
Roads		27	30% reduction
Eroding Banks		1,058	19% reduction
Upland Sediment Sources	**Silviculture**	5	No modeled increase in sediment delivery to the stream or tributaries
	Grazing/Hay Lands	424	22% reduction
	Natural Sources	620	NA
Total Sediment Load/TMDL		2,134	14% reduction

* A significant portion of bank erosion and grazing /hay loads are a natural load

8.3.11 North Fork Big Hole River

The North Fork Big Hole River begins at the confluence of Trail Creek and Ruby Creek on the west side of the upper Big Hole River basin. The stream flows to the northeast for about 15 miles before joining the Big Hole River. Major tributaries also include Tie, Johnson and Mussigbrod creeks.

Most of the sediment produced from bank erosion in this watershed is derived from natural sources or livestock grazing systems. Unpaved roads in North Fork Big Hole River watershed are estimated to contribute about 2 percent of the overall sediment yield, yet may have localized impacts. A large portion of the watershed consists of upland grasses for livestock grazing systems or hay fields and these areas may contribute sediment via human influenced activities. Timber harvest is estimated to contribute less than 1 percent of the overall existing sediment yield.

The TMDL for the North Fork of the Big Hole River is a combination of allocations to reduce sediment production from eroding banks via riparian grazing management from limited reaches of the stream, increasing riparian filtering of upland sediment loads derived from grazing and hay production, a reduction of sediment from roads, and no long term modeled sediment load increase from timber harvest. The overall sediment TMDL is presented as a 14 percent reduction in annual sediment load (**Table 8-15**). Road sanding loads are present but insignificant and should not increase over time.

Table 8-15: Sediment Source Assessment, Allocations and TMDL for North Fork Big Hole River

<table>
<tr><th colspan="2">Sediment Sources</th><th>Current Estimated Load (Tons/Year)</th><th>Sediment LAs</th></tr>
<tr><td colspan="2">Roads</td><td>562</td><td>28% reduction</td></tr>
<tr><td colspan="2">Eroding Banks</td><td>18,948</td><td>24% reduction</td></tr>
<tr><td rowspan="3">Upland Sediment Sources</td><td>Silviculture</td><td>245</td><td>No modeled increase in sediment delivery to the stream or tributaries</td></tr>
<tr><td>Grazing/Hay Lands</td><td>4,386</td><td>23% reduction</td></tr>
<tr><td>Natural Sources</td><td>4,501</td><td>NA</td></tr>
<tr><td colspan="2">Total Sediment Load/TMDL</td><td>28,642</td><td>20% reduction</td></tr>
</table>

* A significant portion of bank erosion and grazing /hay loads are a natural load

8.3.12 Pine Creek

Pine Creek, a tributary of Governor Creek, lies in the southern end of the upper Big Hole River planning area. Its headwaters begin in USFS holding along the Big Hole Divide. It flows for about 4 miles on USFS managed lands before entering private lands.

Pine of the sediment produced from bank erosion in this watershed is derived from natural sources or livestock grazing systems. Sediment produced from eroding banks is one of the largest contributors of sediment and a large portion of this is derived from livestock grazing. Sediment contributions from past timber harvest and silviculture are an insignificant fraction of the existing sediment yield.

The TMDL for Pine Creek is a combination of allocations to reduce sediment production from eroding banks via riparian management, increasing riparian filtering of upland sediment loads derived from grazing and hay production, and no long term sediment load increase from timber harvest or the road system. The overall TMDL is presented as a 46 percent reduction in annual sediment load (**Table 8-16**).

Table 8-16: Sediment Source Assessment, Allocations and TMDL for Pine Creek

Sediment Sources		Current Estimated Load (Tons/Year)	Sediment LAs
Roads		5	No increase
Eroding Banks		604	62% reduction
Upland Sediment Sources	**Silviculture**	0	No modeled increase in sediment delivery to the stream or tributaries
	Grazing/Hay Lands	211	30% reduction
	Natural Sources	141	NA
Total Sediment Load/TMDL		961	46% reduction

* A significant portion of bank erosion and grazing /hay loads are a natural load

8.3.13 Rock Creek

Rock Creek lies on the west side of the Upper Big Hole Valley and flows to the northeast. A recent restoration project restored the lower portion of Rock Creek so it now reaches the Big Hole River, but previously it was incorporated into irrigation ditches.

Most of the sediment produced from bank erosion in this watershed is derived from natural sources or livestock grazing systems. Unpaved roads in Rock Creek watershed are estimated to contribute less than 2 percent of the overall sediment yield, yet may have localized impacts. A large portion of the watershed consists of upland grasses for livestock grazing systems or hay fields and sediment produced from these areas are partially influenced by human activities.

The TMDL for Rock Creek is a combination of allocations to reduce sediment production from eroding banks via riparian grazing management from limited reaches of the stream, increasing riparian filtering of upland sediment loads derived from grazing and hay production, a reduction of sediment from roads, and no long term sediment load increase from timber harvest. The overall sediment TMDL is presented as a 31 percent reduction in annual sediment load (**Table 8-17**).

Table 8-17: Sediment Source Assessment, Allocations and TMDL for Rock Creek

Sediment Sources		Current Estimated Load (Tons/Year)	Sediment LAs
Roads		112	32% reduction
Eroding Banks		4,909	36% reduction
Upland Sediment Sources	**Silviculture**	21	No modeled increase in sediment delivery to the stream or tributaries
	Grazing/Hay Lands	1,849	20% reduction
	Natural Sources	193	NA
Total Sediment Load/TMDL		7,084	31% reduction

* A significant portion of bank erosion and grazing /hay loads are a natural load

8.3.14 Ruby Creek

Ruby Creek lies on the west side of the Upper Big Hole Valley and flows to the northeast. A recent restoration project restored the lower portion of Ruby Creek so it now reaches the Big Hole River, but previously it was incorporated into irrigation ditches.

About 50 percent of the sediment production from this watershed is derived from bank erosion. Most of the sediment produced from bank erosion in this watershed is derived from natural sources and to a lesser extent from livestock grazing systems. Unpaved roads in Ruby Creek watershed are estimated to contribute slightly more than 3 percent of the overall sediment yield. A large portion of the watershed consists of upland grasses for livestock grazing systems or hay fields and sediment produced from these areas are partially influenced by human activities.

The TMDL for Ruby Creek is a combination of allocations to reduce sediment production from eroding banks via riparian grazing management from limited reaches of the stream, increasing riparian filtering of upland sediment loads derived from grazing and hay production, a reduction of sediment from roads, and no long term sediment load increase from timber harvest. The overall sediment TMDL is presented as a 10 percent reduction in annual sediment load (**Table 8-18**).

Table 8-18: Sediment Source Assessment, Allocations and TMDL for Ruby Creek

Sediment Sources		Current Estimated Load (Tons/Year)	Sediment LAs
Roads		163	21% reduction
Eroding Banks		2,593	6% reduction
Upland Sediment Sources	**Silviculture**	21	No modeled increase in sediment delivery to the stream or tributaries
	Grazing/Hay Lands	1,170	23% reduction
	Natural Sources	844	NA
Total Sediment Load/TMDL		4,791	10% reduction

* A significant portion of bank erosion and grazing /hay loads are a natural load

8.3.15 Steel Creek

Steel Creek is a tributary of the Big Hole River originating in the Pioneer Mountains on the east side of the upper Big Hole River valley. The upper, forested portion of the watershed lies on the Beaverhead Deerlodge National Forest. The remaining 22 percent of the watershed is on lower elevation private lands.

Over 70 percent of the sediment production from this watershed is derived from bank erosion. Most of the sediment produced from bank erosion in this watershed is derived from natural sources and livestock grazing systems. Unpaved roads in Steel Creek watershed are estimated to contribute less than 3 percent of the overall sediment yield. A large portion of the watershed consists of upland grasses for livestock grazing systems or hay fields and sediment produced from these areas are partially influenced by human activities.

The TMDL for Steel Creek is a combination of allocations to reduce sediment production from eroding banks via riparian grazing management, increasing riparian filtering of upland sediment loads derived from grazing and hay production, a reduction of sediment from roads, and no long term sediment load increase from timber harvest. The overall sediment TMDL is presented as a 34 percent reduction in annual sediment load (**Table 8-19**).

Table 8-19: Sediment Source Assessment, Allocations and TMDL for Steel Creek

Sediment Sources		Current Estimated Load (Tons/Year)	Sediment LAs
Roads		194	31% reduction
Eroding Banks		6,224	39% reduction
Upland Sediment Sources	**Silviculture**	8	No modeled increase in sediment delivery to the stream or tributaries
	Grazing/Hay Lands	1,103	22% reduction
	Natural Sources	552	NA
Total Sediment Load/TMDL		8,081	34% reduction

* A significant portion of bank erosion and grazing /hay loads are a natural load

8.3.16 Swamp Creek

Swamp Creek is a tributary of the Big Hole River flowing to the northeast from the west side of the basin. Unlike other streams in the watershed, Swamp Creek originates in the valley and lacks headwaters in the Beaverhead National Forest.

About 70 percent of the sediment production from this watershed is derived from bank erosion. Most of the sediment produced from bank erosion in this watershed is derived from natural sources and livestock grazing systems. Unpaved roads in the Steel Creek watershed are estimated to contribute about 1 percent of the overall sediment yield. A large portion of the watershed consists of upland grasses for livestock grazing systems or hay fields and sediment produced from these areas are partially influenced by human activities.

The TMDL for Steel Creek is a combination of allocations to reduce sediment production from eroding banks via riparian grazing management, increasing riparian filtering of upland sediment loads derived from grazing and hay production, and a reduction of sediment from roads. The overall sediment TMDL is presented as a 27 percent reduction in annual sediment load (**Table 8-20**).

Table 8-20: Sediment Source Assessment, Allocations and TMDL for Swamp Creek

Sediment Sources		Current Estimated Load (Tons/Year)	Sediment LAs
Roads		67	33% reduction
Eroding Banks		4,123	30% reduction
Upland Sediment Sources	**Silviculture**	6	No modeled increase in sediment delivery to the stream or tributaries
	Grazing/Hay Lands	1,424	23% reduction
	Natural Sources	204	NA
Total Sediment Load/TMDL		5,824	27% reduction

* A significant portion of bank erosion and grazing /hay loads are a natural load

8.3.17 Tie Creek

Tie Creek is a montane tributary of the North Fork Big Hole River on the west side of the basin. It flows about 14 miles with all but the last 2 miles within the Beaverhead National Forest. Eroding banks contribute approximately half of the sediment to the watershed. Most of the sediment produced from bank erosion in this watershed is derived from natural sources or livestock grazing systems. Unpaved roads in Tie Creek watershed are estimated to contribute slightly more than 2 percent of the overall sediment yield. Sediment contributions from past timber harvest is estimated at about 4 percent of the existing sediment yield.

The TMDL for Tie Creek is a combination of allocations to reduce sediment production from eroding banks via riparian management, increasing riparian filtering of upland sediment loads derived from grazing and hay production, a reduction of sediment from roads, and no long term sediment load increase from timber harvest. The overall TMDL is presented as an 18 percent reduction in annual sediment load (**Table 8-21**).

Table 8-21: Sediment Source Assessment, Allocations and TMDL for Tie Creek

Sediment Sources		Current Estimated Load (Tons/Year)	Sediment LAs
Roads		40	18% reduction
Eroding Banks		876	25% reduction
Upland Sediment Sources	**Silviculture**	79	No modeled increase in sediment delivery to the stream or tributaries
	Grazing/Hay Lands	312	27% reduction
	Natural Sources	464	NA
Total Sediment Load/TMDL		1,771	18% reduction

* A significant portion of bank erosion and grazing /hay loads are a natural load

8.3.18 Upper and Lower Segments of Trail Creek

The Trail Creek drainage is the largest montane watershed in the west side of the upper Big Hole River planning area. It originates along the Continental Divide and Idaho border then flows east to its confluence with the North Fork Big Hole River. DEQ lists two segments of Trail Creek as impaired. The upper segment extends from its headwaters until its confluence with Joseph Creek. The lower segment covers the remaining length of this stream to the confluence with Ruby Creek where it forms the North Fork of the Big Hole River.

8.3.18.1 Upper Trail Creek TMDL (watershed above Joseph Creek)

Eroding banks are estimated to contribute about 60 percent of the sediment to the watershed. Most of the sediment produced from bank erosion in this watershed is derived from natural sources, transportation effects or past livestock grazing systems. Unpaved roads in the upper Trail Creek watershed are estimated to contribute between 1 and 2 percent of the overall sediment yield. Sediment contributions from past timber harvests are insignificant.

The TMDL for upper Trail Creek is a combination of allocations to reduce sediment production from eroding banks via riparian management, increasing riparian filtering of upland sediment loads derived from grazing and hay production, a reduction of sediment from roads, and no long term sediment load increase from timber harvest or road sanding. The overall TMDL is presented as a 20 percent reduction in annual sediment load (**Table 8-22**).

Table 8-22: Sediment Source Assessment, Allocations and TMDL for Upper Trail Creek

Sediment Sources		Current Estimated Load (Tons/Year)	Sediment LAs
Roads		32	16% reduction
Eroding Banks		1,283	24% reduction
Upland Sediment Sources	**Silviculture**	4	No modeled increase in sediment delivery to the stream or tributaries
	Grazing/Hay Lands	325	No increase
	Natural Sources	371	NA
Total Sediment Load/TMDL		2,015	16 % reduction

* A significant portion of bank erosion and grazing/hay loads are a natural load

8.3.18.2 Lower Trail Creek TMDL (whole watershed)

Eroding banks are estimated to contribute over half of the sediment to the watershed. Most of the sediment produced from bank erosion in this watershed is derived from natural sources, transportation effects or past livestock grazing systems. Unpaved roads in the upper Trail Creek watershed are estimated to contribute about 2 percent of the overall sediment yield. Sediment contributions from past timber harvest is estimated at about 4 percent of the existing sediment yield.

The TMDL for lower Trail Creek is a combination of allocations to reduce sediment production from eroding banks via riparian management, increasing riparian filtering of upland sediment loads derived from grazing and hay production, a reduction of sediment from roads, and no long term sediment load increase from timber harvest or road sanding. The overall TMDL is presented as a 12 percent reduction in annual sediment load (**Table 8-23**). This reduction may seem low but much of the sediment in the stream is due to past fire, silvicutlure and grazing activities and needs time to move via flood events. Also sediment loads from fire were quite high and may overshadow some of the more continuous human caused sources.

Table 8-23: Sediment Source Assessment, Allocations and TMDL for Trail Creek

Sediment Sources		Current Estimated Load (Tons/Year)	Sediment LAs
Unpaved Roads		101	29% reduction
Hwy 43 Road Sanding		2.4	No increase
Eroding Banks		3,126	17% reduction
Upland Sediment Sources	**Silviculture**	65	No modeled increase in sediment delivery to the stream or tributaries
	Grazing/Hay Lands	788	66% reduction
	Natural Sources	1,313	NA
Total Sediment Load/TMDL		5,395	12% reduction

* A significant portion of bank erosion and grazing /hay loads are a natural load

8.4 Future Growth and New Sediment Sources

A limited potential for new sediment sources from future activities in the upper Big Hole Valley and surrounding mountains exists. Future developments within the Upper and North Fork Big Hole River TPA may have the potential to increase sediment loads to the stream network. Potential future development includes timber harvest, increased grazing, road construction and maintenance, new subdivision development, and increased recreational pressure. None of these activities currently have a sediment allocation within the TMDLs. If these activities cause significant sediment production, they will need to be considered in updated allocation and restoration approaches. If these sources arrive in the watershed they should use all reasonable land, soil and water conservation practices that reduce erosion.

Throughout the Upper and North Fork Big Hole Watersheds, care should be taken to avoid practices such as new road development or home/cabin site building near streams, including flood plains and river migration areas. Other practices that should be avoided are the addition of riprap along streambanks, placement of undersized culverts, and the removal of riparian vegetation in the stream corridors. Other negative impacts with the potential to increase sediment loads may arise on a site specific basis. If new, significant human caused sources of sediment are proposed in the watershed, a new allocation approach should be considered.

8.5 Uncertainty and Adaptive Management

The source assessments used as the basis for the percent reduction allocation assessed all sizeable sediment sources, but a few small sources may have been overlooked because of budgetary and temporal limitations of the TMDL project. The EPA sediment TMDL development guidance for source assessment states that the basic source assessment procedure includes compiling an inventory of all sources of sediment to the water body and using one or more methods to determine the relative magnitude of source loading, focusing on the primary and controllable sources of loading (EPA 1999). Additionally, regulations allow that loadings "...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)). If the allocations are followed, sediment loads are expected to be reduced to a degree that the sediment targets are met and beneficial uses are no longer impaired.

Because of the uncertainty in the source assessment, the allocations are established as percent load reductions rather than absolute load reductions. Sediment source assessment results are useful for determining the largest sources within each watershed and are useful, along with consideration of restoration costs, to determine an allocation strategy based on economic costs and environmental benefits. Due to current BMP implementation, allocated percent reductions may not be feasible at all locations. Conversely, the source assessment did not account for riparian buffers and associated reductions in sediment loading from upland erosion; the existing load from upland erosion may be lower due to current riparian conditions, and additional reductions will be achievable in many areas with the improvement of riparian buffers. Although the bank erosion assessment estimated percent reductions via improved riparian habitat, some eroding banks may require bank stabilization as well.

Uncertainty in loading estimates is addressed through an adaptive management approach where the TMDL and allocations from this document can be revised as additional information is collected. Adaptive management is part of the MOS and requires long-term monitoring to track BMPs and stream conditions to determine if targets have been achieved. This approach allows management recommendations and practices to be revised if targets have not been met. Monitoring recommendations are detailed in **Section 11.0.**

The loads and allocations established in this document are meant to apply to recent conditions of natural background and natural disturbance. Under some natural conditions, such as large wildfires or extreme flow events, it may not be possible to satisfy all targets, loads, and allocations because of natural short term background sediment load pulses. The goal is to ensure that management activities are undertaken to achieve loading approximate to the TMDLs within a reasonable time frame and to prevent significant longer term excess loading during recovery from significant natural events.

Noticeable improvement in habitat and reduction in sediment loading will not occur until most types of restoration mechanisms or management based activities have been in place for several years or more. Habitat improvements, due to grazing, BMPs should be observable within 3 to 5 years after project implementation. Water quality improvement may not be noticeable within the first several years, as it may take up to 10 years for sediment to flush through the system, depending on flow management, climate, and the magnitude of excess deposition in different stream reaches. In fact, some of the TMDLs have very low reductions due to the fact that many of the sources have been addressed during the past decade but long term effects of past sediment sources are still noticeable in the stream. Therefore, sediment reductions to meet the allocations and targets will be a long-term goal.

8.6 Sediment Margin of Safety and Seasonality

Incorporating a margin of safety (MOS) is a required component of TMDL development. The margin of safety (MOS) accounts for the uncertainty between pollutant loading and water quality and is intended to ensure that load reductions and allocations are sufficient to sustain conditions that will support beneficial uses. 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 (EPA, 1999). This plan incorporates an implicit MOS in a variety of ways:

- The use of multiple targets to help verify that sediment impacts to beneficial uses are reviewed thoroughly for assessing standards attainment after TMDL implementation.
- The use of supplemental indicators, including biological indicators, to help verify beneficial use support determinations and assess standards attainment after TMDL implementation.
- Standards, targets and TMDLs that address both course and fine sediment delivery.
- The supplemental indicators may also provide an early warning method to identify pollutant-loading threats, which may not otherwise be identified, if targets are not met.
- Conservative assumptions were used for the source assessment process, including erosion rates, sediment delivery ratio, and BMP effectiveness (see **Appendices A, G, and H**).
- Consideration of seasonality (discussed in **Section 5.3**).
- The adaptive management approach evaluates target attainment and allows for refinement of load allocation, targets, modeling assumptions, and restoration strategies to further reduce uncertainties associated with TMDL development (discussed below and in **Section 8.5**).
- The use of “naturally occurring” sediment loads as described in ARM 17.30.602(17) to establish the TMDLs and allocations. This includes an allocation process that addresses all known human sediment causing activities, not just the significant sources.

Seasonal sediment impact to aquatic life is taken into consideration in the analysis within this document. Fine sediment deposition may impact fish spawning seasonally but impact aquatic insect food sources annually. Pool filling by either fine or course sediment usually impacts the quantity of adult fish habitat and thus, the adult fish population constantly throughout the year. Annual loads are reported within the main body of this document and are appropriate because the impacts of delivered sediment are a long term impact once sediment enters the stream network. It may take years for sediment loads to move through a watershed. Daily loads are provided in the appendix to meet EPA requirements but are not especially useful for watershed restoration within this watershed.

SECTION 9.0
NUTRIENT SOURCE ASSESSMENT, TMDLS AND ALLOCATIONS

9.1 Introduction and Background Information

Nutrients are elements or compounds essential for the growth and survival of organisms. Most living cells require large amounts of nutrients, such as nitrogen, phosphorus, carbon, hydrogen, oxygen, potassium, and calcium (macronutrients), and small amounts of micronutrients such as manganese, copper, and chloride. Nutrients circulate in cycles that involve exchanges between the organic and inorganic components of the environment, as well as between plants and animals. In these cycles, each nutrient undergoes chemical transformations that determine its availability to different organisms. Therefore, the supply of nutrients within an ecosystem has a substantial influence on both the abundance of plant and animal life and the types and variety of species that can inhabit an ecosystem.

Human activities can increase the biologically available supply of two key nutrients, nitrogen and phosphorus. An oversupply of nutrients, known as eutrophication, encourages excessive plant production in aquatic ecosystems. Several impairments often result from excessive plant growth related to nutrient loading. Over stimulation of benthic algae can cause aesthetic problems. Also, decaying or alive plant matter may stimulate too much respiration or decomposition which consumes oxygen when plants are not producing oxygen via photosynthesis at night. Eventually, dissolved oxygen is depleted, often to the point where fish and other species can no longer survive.

Framework Nutrient TMDLs

It is acknowledged that existing nutrient data for the Upper – North Fork Big Hole TPA is limited and targets are based on a numeric translation of Montana's narrative nutrient standards. As a result, the extent of the nutrient problems is not defined as well as would be desirable although controllable sources of nutrients in the watershed are fairly straightforward to understand. The following nutrient TMDLs and allocations are presented as a framework starting point from which watershed stakeholders can voluntarily begin to address water quality problems in the Upper – North Fork Big Hole TPA. The nutrient targets are considered interim values that may need to be revised in the future, and compliance with the targets is currently considered voluntary. An adaptive management strategy to facilitate revision of the nutrient targets, TMDLs, and allocations is presented in **Section 9.5**.

Nutrients are among the pollutants of concern for a number of streams in the Upper/NF Big Hole River TMDL planning area (**Table 1-1**). Although ten streams have been listed for nutrients in this area, most were listed for nutrients as probable causes of impairment after this TMDL project initiated. Two watersheds were included in the nutrient assessment scope of this TMDL project: Steel and Rock Creeks. Rock Creek nutrient assessment work quickly became very complex and out of the original project scope due to irrigation water management activities, and therefore nutrient TMDL completion for this stream is postponed for the time being. Alternatively, Francis Creek is a tributary to Steel Creek and was listed as likely impaired due to nutrients after project initiation. Because it is a tributary to Steel Creek and modeling for this area was already completed, this TMDL was easily completed as part of this TMDL project. Nutrient TMDLs are provided for Steel and Francis Creeks in this document. Other nutrient listings will be addressed in the future according to Montana's TMDL completion schedule.

9.2 Nutrient Source Assessment Techniques

Methods to develop an inventory of sources of nutrient loading included field investigations and the aerial survey completed in the first portion of TMDL planning (Confluence et al. 2003). Specific activities consisted of field reconnaissance, nutrient sampling (**Section 5**), evaluations of riparian community structure and composition (**Appendix C**), bank erosion assessments(**Appendix C**), interviews with agency personnel regarding farming and grazing practices, and Generalized Watershed Loading Functions nutrient modeling (GWLF) (**Appendix I**).

9.2.1 Initial Nutrient Assessment Planning

Initial efforts in the upper/NF Big Hole River TMDL planning area allowed determination of broad categories of sources attributable to nutrient enrichment in basin streams with agriculture emerging as the only identifiable factor (Confluence et al. 2003). No point sources are present. Residential development, municipalities, and forestry practices are unlikely to contribute excess nutrients to streams for several reasons. Because of its low population density of humans, especially adjacent to nutrient-listed streams, nutrient enrichment from residential development is a negligible component of the human-caused load. Septic systems and fertilized lawns are a limited source of nutrients; however, aerial photo analyses did not detect residential development in proximity to nutrient listed streams. Logging can result in short-lived spikes in nutrient loading (Likens et al. 1967); however, timber harvest activities in the basin are relatively old or currently at small scale, making this an unlikely source. Therefore, agricultural sources are the sole attributable significant human caused category of anthropogenic nutrient loading to nutrient listed streams that was further investigated. Sources of nutrients from agricultural activities include accelerated bank erosion from livestock, reduced riparian filtering form livestock grazing and browsing, limited areas of upland vegetation reduction from livestock grazing, and fertilizer applications.

Field reconnaissance efforts to inventory sources of nutrient sources in the upper Big Hole River planning area noted a striking feature of the basin that presents an obstacle in identifying sources and evaluating their relative contributions. The extent of water management, with flows diverted and transported in a complex network of irrigation ditches, presents an impediment to identifying specific agricultural source areas using water chemistry and discharge assessments. In some cases, ditches transport water across sub-basins, thereby obscuring original source areas. Water, along with nutrients, are diverted and reused via the irrigation systems. Furthermore, flood irrigation practices result in exposure of water to areas with varying potential to contribute nutrients. The tributary watersheds where nutrient TMDLs are developed do contain irrigation infrastructure and irrigated pastures, but do not contain large inter-basin water transfer. A couple nutrient TMDLs were deferred for completion at a later timeframe because of the poor understanding about irrigation network and known inter-basin water transfers with only few water chemistry results for supporting the TMDL.

Despite the inherent difficulties in identifying sources of nutrient loading in the upper Big Hole, a number of categories of nutrient sources are obvious. Livestock are a significant potential source with accumulations of animal wastes across the landscape. Manure is a source of both nitrogen and phosphorus (Gilbertson et al. 1979) and contributes to eutrophication in streams. Also, fertilizer is used on hay fields and agricultural activities reduce the vegetation filtering capacity along streams. Grazing impacts also can reduce ground cover and stimulate higher overland and streambank erosion, and thus nutrients associated with soil loss. Natural landscape sources are also present; these include natural forest, grass and shrub land erosion and groundwater pathways. A land use and land cover based modeling approach was used to assess these human caused sources of nutrients along with other natural sources at a watershed scale.

9.2.2 Nutrient Watershed Source Assessment Modeling and Supporting Information

The Generalized Watershed Loading Functions Model (GWLF) uses weather, soils, instream nutrient, stream discharge, land cover types, agricultural statistics, riparian condition information, fertilizer use, and streambank erosion information for model setup and calibration (**Appendix I**). The model was calibrated using data from the USGS site near Melrose on the Big Hole River and validated using data from a USGS gauge in Willow Creek. After calibration, and existing condition model runs, the model was used for restoration scenario nutrient load assessments. The following paragraphs provided are about key data relative to human influenced sources used within the model, although **Appendix I** provides more detailed modeling information.

Riparian buffers serve as a nutrient filtering zone through a number of processes (**Appendix J**). Nutrient listed streams varied in terms of the potential for riparian buffers to filter and take up nutrients (**Table 9-1**). Lower portions of Steel Creek and all of Francis Creek rated as having low filtering potential due to the relatively high proportions of stream with sparse riparian cover observable from aerial photos and verified during field monitoring. This information, along with riparian condition information on USFS land, was used to determine riparian filtration function inputs into the GWLF model. Both existing and restored riparian filtration function were considered within the model. Bank erosion was also considered within the model and riparian function, aerial photo and bank erosion assessments were used to estimate existing and restored bank erosion conditions within the GWLF model in a similar manner that the riparian filtering function was assessed.

Table 9-1: Potential for riparian buffers to mitigate nutrient loading though filtering and uptake based on analyses of aerial imagery and vegetation indicators which influence nutrient filtering capacity along stream corridors.

Stream	Percent of Stream within Qualitative Riparian Cover Classes Observed from Aerial Imagery (Non-forested reaches)				Nutrient Filtering Capacity Indicators Measured on Stream Banks (Number of Assessed Reaches)			Existing Potential to Mitigate Nutrient Loads
	Dense	Moderate	Moderate to Sparse	Sparse	Percent Shrubs along	Percent Bare ground	Percent Shrubs	
Francis Creek	0	0	0	100	0 (1)	4 (1)	0 (1)	Low
Steel Creek	0	24	0	76	27 (2)	9 (2)	15 (2)	Low to Moderate

Fertilizer application rates were determined in coordination with NRCS, the Big Hole Watershed Committee, and local ranchers. Recent increases in costs, along with efforts to restore fluvial arctic grayling, have brought about a recent fertilizer application reduction. Pre winter 2007 application fertilizer rates were used for calibration since calibration data were from this timeframe and post 2007 rates are used for fertilizer reduction scenarios. Domestic animal numbers on the landscape were derived using 2000 census data and also verified in a few watersheds using USFS information and coordination with the local USFS range manager.

The nutrient model likely has underestimated nutrient loads in Francis and Steel Creek due to irrigated hay and pasture, which include fertilizer applications. Aerial photos were compared to the land cover data set used in the model and irrigated hay and pasture is underrepresented within the land cover data in the upper Big Hole Valley. The likely reason for this was that land cover images were attained during haying season when fields were dry in the upper Big Hole Valley. Therefore, the nutrient contributions from this source are likely higher than those identified in the source assessment and likely fall under the grassland load in the source assessment.

Upland erosion rates were assessed in the model via use of cover factors which represent existing conditions and those that represent conditions of healthy grass and shrubland range conditions. Domestic animal stocking rates were determined using data from U.S. Agricultural Statistics Service. Nutrient loads from animal waste are incorporated into each landscape they inhabit.

9.3 Francis Creek

See **Section 5.0** for Francis Creek's existing nutrient conditions assessment and nutrient targets.

9.3.1 Nutrient Source Assessment Results

Nitrogen source assessment results indicate forest land as the most major contributor of nitrogen, yet this source is mostly natural except for limited grazing (**Figure 9-1**). Grassland and shrubland combined make the next largest source area and include natural background nitrogen loads but also the human influence of reduced vegetation from grazing. Another contribution of nitrogen from grass and shrub lands comes from domestic animal waste. Bank erosion, both natural and unnatural, is another significant source of nitrogen to the stream. Hay/pasture nitrogen sources are likely higher than identified and will also be considered in TMDL allocations and restoration approaches. Suburban lands are a small source.

Francis Creek's phosphorus source assessment results reveal forest land as the most major contributor, yet this source is mostly natural except for limited grazing. Grassland and shrubland combined make the next largest phosphorus source and include both natural background and the human influence of reduced upland vegetation from grazing systems which slightly elevates erosion. Bank erosion is the next largest source of phosphorus to the stream, although it is likely one of the more controllable human influenced sources. Bank erosion is highly influenced by domesticated livestock riparian grazing. Hay/pasture areas are likely a larger contributor of phosphorus than identified and will also be considered in TMDL allocations and restoration approaches. Suburban areas are a very small source of phosphorus in this watershed. Farm animal waste via grazing systems contributes a very minor contribution of phosphorus.

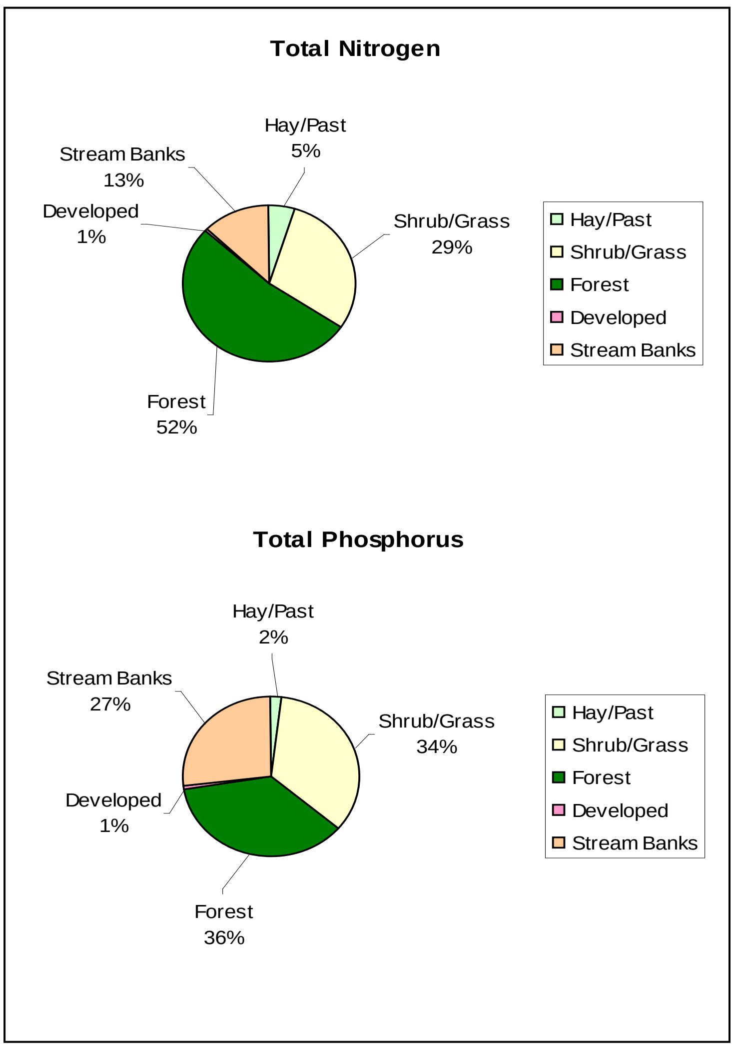


Figure 9-1: Francis Creek Nutrient Source Assessment Results

9.3.2 Francis Creek Nutrient TMDLs

Both total nitrogen and total phosphorus TMDLs will be provided for Francis Creek because the data available in this watershed is not robust and the restoration approaches in this landscape will address both nitrogen and phosphorus reductions. The total nitrogen TMDL is provided in **Equation 9-1** and the total phosphorus TMDL is provided in **Equation 9-2**. Future conditions will be considered meeting the TMDL if there is less than a 20 percent exceedance rate as long as exceedances are random during the summer months. This exceedance rate allows for natural variability yet will protect against nutrient conditions that impact any use of the water. The TMDLs are applied only to the summer growing season during July, August and September.

Equation 9-1.

Total Nitrogen TMDL = CFS*1.72

Where: CFS = Discharge in cubic feet per second

1.72 = Conversion factors combined with total nitrogen target from Section 4.0

Equation 9-2.

Total Phosphorus TMDL = CFS*0.264

Where: CFS = Discharge in cubic feet per second

1.72 = Conversion factors combined with total phosphorus target from Section 4.0

9.3.3 Francis Creek Nutrient Allocations

Comparison of the nutrient TMDLs to the GWLF modeling efforts provide an example of how existing and restored watershed conditions compare to the TMDL. The model estimates long term average stream flow and water quality conditions over many years. **Figure 9-2** provides an estimate of existing total nitrogen and phosphorus loads compared to the TMDLs for the calibrated hydrology in Francis Creek Watershed. While viewing the modeling results keep in mind that modeling efforts show average flow and water quality conditions over a multiple year period and the TMDL calls for 80 percent compliance rate. Even so, comparing the modeling results of both existing and restored conditions to the TMDL is very useful because it can indicate if the restoration approaches will likely achieve the TMDL and water quality targets. While making comparisons of the TMDL and model results, keep in mind that the TMDL must be met 80 percent of the time, not approximately 50 percent of the time as **Figure 9-2** may imply because the GWLF model was built upon average conditions. To account for this difference, the TMDL allocation approach will use the results of the modeled restoration implementation scenario where all reasonable land, soil and water conservation practices are in place, where the estimated median summer loads are about 1/3rd lower than the TMDL. This provides an explicit margin of safety in the TMDL and is expected to compensate for the frequency differences in the TMDL and modeling approaches.

Estimated load reductions within the GWLF model are based on agricultural restoration approaches. Reasonable agricultural restoration practices related to grazing and hay production included in the model are riparian vegetation restoration and management, fertilizer management and upland grazing management. The restoration approaches affect both nutrient production and filtering.

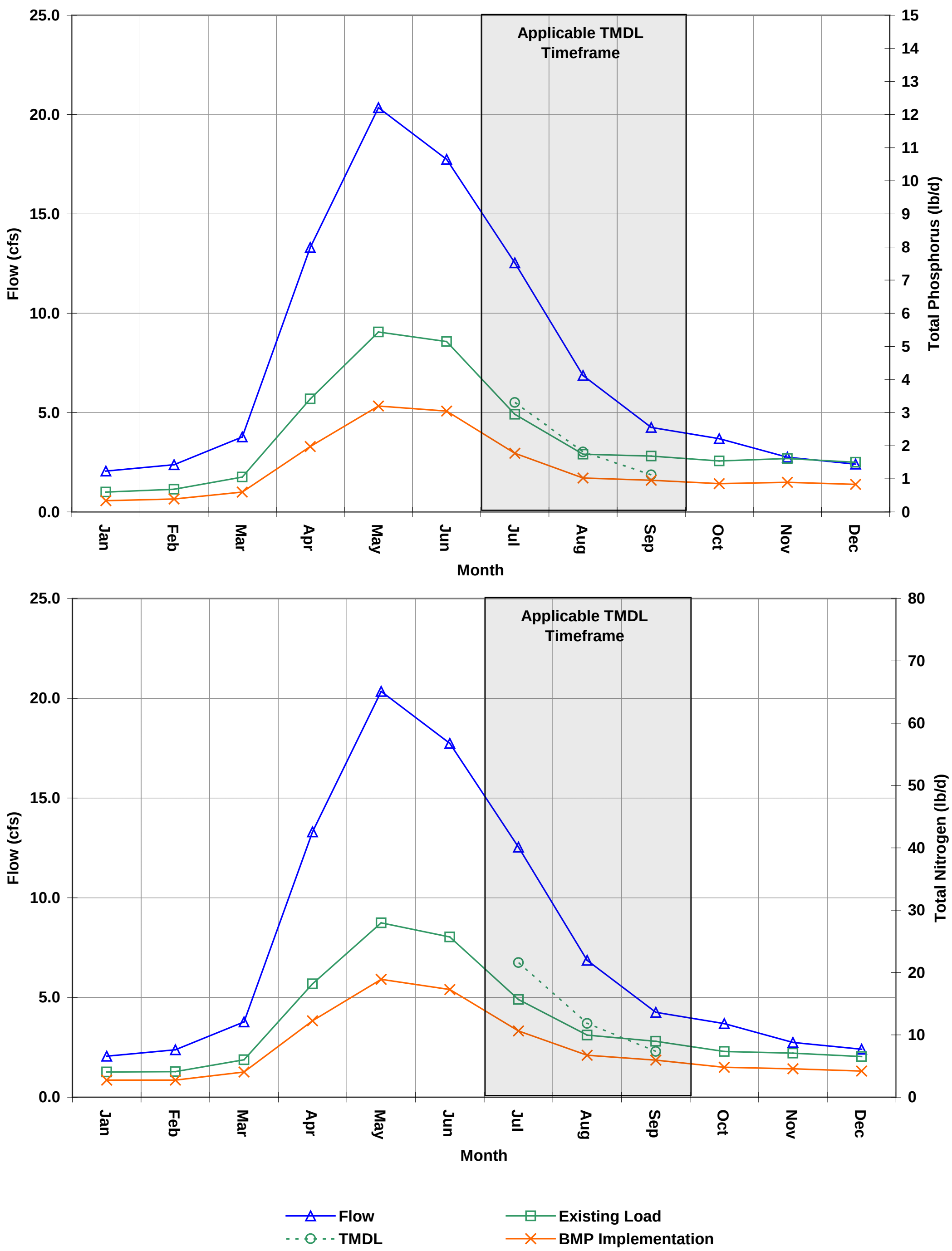


Figure 9-2: Long term average GWLF total nitrogen and phosphorus load modeling results for Francis Creek Watershed.

GWLF modeling is used to determine nitrogen and phosphorus reductions from each of the identified source reductions needed to meet the TMDL (**Appendix I**). Load reductions identified in modeling scenarios are based upon applying reasonable agricultural BMPs such as riparian vegetation restoration, riparian zone protections from grazing impacts, managing fertilizer applications rates, and moving hay production from riparian zone areas. These practices will reduce nutrients imported into the watershed, reduce bank erosion, and increase riparian filtering treatment of runoff and groundwater. Francis Creek's nitrogen and phosphorus load allocations are provided in **Table 9-2** and **9-3** respectively. Allocations are presented by source area and also by the ability of riparian areas to filter nutrients as they move toward streams. Model results of the restoration scenarios indicate that both nitrogen and phosphorus loads can be reduced the most by promoting natural riparian vegetation regrowth by managing grazing and moving hay production from these areas. Specific restoration approaches for riparian areas will depend upon how heavily impacted areas have been historically.

Allocations are provided for a yearly timeframe in the main document because the nonpoint source, landscape scale, restoration approaches will reduce nutrient conditions year round, even though the nutrient TMDL is provided only for the summer growing season. The yearly allocations will provide monthly BMP implementation loads during the summer time which are provided in **Figure 9-2.** The estimated summer monthly loads after restoration implementation are lower than the TMDL. Also, a yearly allocation approach will address sources of nutrients if they are introduced to streams during runoff but stored in channel and available during the summer growing season. All human caused significant sources are considered in the allocation approach and therefore the remaining load after implementation of restoration approaches is considered naturally occurring.

An example of the allocation approach for reducing hay and pasture nitrogen loading in Francis Creek is provided. The existing load for Hay/Pasture is 219 pounds. With fertilizer management in this source area, the existing load could be reduced by 17 lbs to 202 lbs. Of this 202 lbs, adjacent healthy stream side filter strips have the potential to reduce this load by an additional 50% down to 101 lbs, which is then the source area allocation to Hay/Pasture. This shows that just for this source area, the TN reduction can be greater than 50 percent with most of the reduction coming from improved riparian conditions (**Figure 9-3**).

Upland & Riparian BMP Allocation Scenario Example

Source	Existing Condition	Fertilizer Reduction and Grazing Management	Increased Riparian Buffer Filtration	Delivered Nitrogen Load
Hay/Pasture	219 lbs/yr	202 lbs/yr	50% reduction	101 tons/yr

Figure 9-3. Riparian Zone Runoff and Groundwater treatment pathways (from Environment Southland, New Zealand)

Table 9-2: Francis Creek Average Annual Nitrogen Source Assessment and Restoration Load Estimation (allocation).

Source Area	Associated Human Activities	Existing Tot. N (lbs)	Source Area Restoration Approach (reduction in lbs)	Source Area Allocated Tot. N (lbs)	Pollutant Filtering via Riparian Vegetation Improvement (reduction in lbs)	Total Allocated Load From Source (lbs)
Hay/Past	Grazing Hay Production Fertilizer	219	Fertilizer/Grazing Management 17	202	50% 101	101
Shrub and Grassland	Grazing	1275	Upland Grazing Management 89	1186	50% 593	593
Forest	Grazing	2259	NA	2259	15% 338	1920
Developed	Suburban	25	NA	25	0	25
Streambanks	Grazing Hay encroachment	549	Riparian Vegetation Restoration and Grazing Management 143	406	NA	406
Point Sources	Waste Load Allocation	0	NA	0	0	0
Future Sources*	All	0	NA	0	0	0
Total Estimated Annual Load		4326	248	4078	1033	3045
Estimated overall % reduction			6%		25%	30%

*If future nutrient sources occur, the allocation approach should be updated with new sources considered.

Table 9-3: Francis Creek Average Annual Phosphorus Source Assessment and Restoration Load Estimation (allocation).

Source Area	Associated Human Activities	Existing Tot. P (lbs)	Source Area Restoration Approach (reduction in lbs)	Source Area Allocated Tot. P (lbs)	Pollutant Filtering via Riparian Vegetation Improvement (reduction in lbs)	Total Allocated Load From Source (lbs)
Hay/Past	Grazing Hay Production Fertilizer	19	Fertilizer/Grazing Management 11	8	50% 4	4
Shrub and Grassland	Grazing	285	Upland grazing management 37	248	50% 124	124
Forest	Grazing	301	NA	301	15% 45	256
Developed	Suburban	5	NA	5	0	5
Streambanks	Grazing Hay encroachment	227	Riparian Vegetation restoration and grazing management 59	168	NA	168
Point Sources	Waste Load Allocation	0	NA	0	0	0
Future Sources*	All	0	NA	0	0	0
Total Estimated Annual Load		836	107	729	173	557
Estimated overall % reduction (not a TMDL)			13%		24%	33%

*If future nutrient sources occur, the allocation approach should be updated with new sources considered.

9.4 Steel Creek

See **Section 5.0** for Steel Creek's existing nutrient conditions assessment and nutrient targets.

9.4.1 Steel Creek Nutrient Source Assessment

Nitrogen source assessment results indicate forest land as the most major contributor of nitrogen, yet this source is mostly natural except for limited grazing (**Figure 9-4**). Grassland and shrubland combined make the next largest source area and include natural background nitrogen loads but also the human influence of reduced vegetation from grazing. Another contribution of nitrogen from grass and shrub lands comes from domestic animal waste. Bank erosion, both natural and unnatural, is another significant source of nitrogen to the stream. Hay/pasture nitrogen sources are likely higher than identified and will also be considered in TMDL allocations and restoration approaches. Suburban lands are a small source. Nitrogen produced from animal waste is a smaller, but significant, portion of the load from grass, shrub and hay/pasture lands.

Steel Creek's phosphorus source assessment results reveal forest land as the most major contributor, yet this source is mostly natural except for limited grazing. Grassland and shrubland combined make the next largest phosphorus source and include both natural background and the human influence of reduced upland vegetation from grazing systems which slightly elevates erosion. Bank erosion is the next largest source of phosphorus to the stream although it is likely one of the more controllable human influenced sources. Bank erosion is highly influenced by domesticated livestock riparian grazing. Hay/pasture areas are likely a larger contributor of phosphorus than identified and will also be considered in TMDL allocations and restoration approaches. Suburban area is a very small source of phosphorus in this watershed. Farm animal waste via grazing systems contributes a very minor contribution of phosphorus.

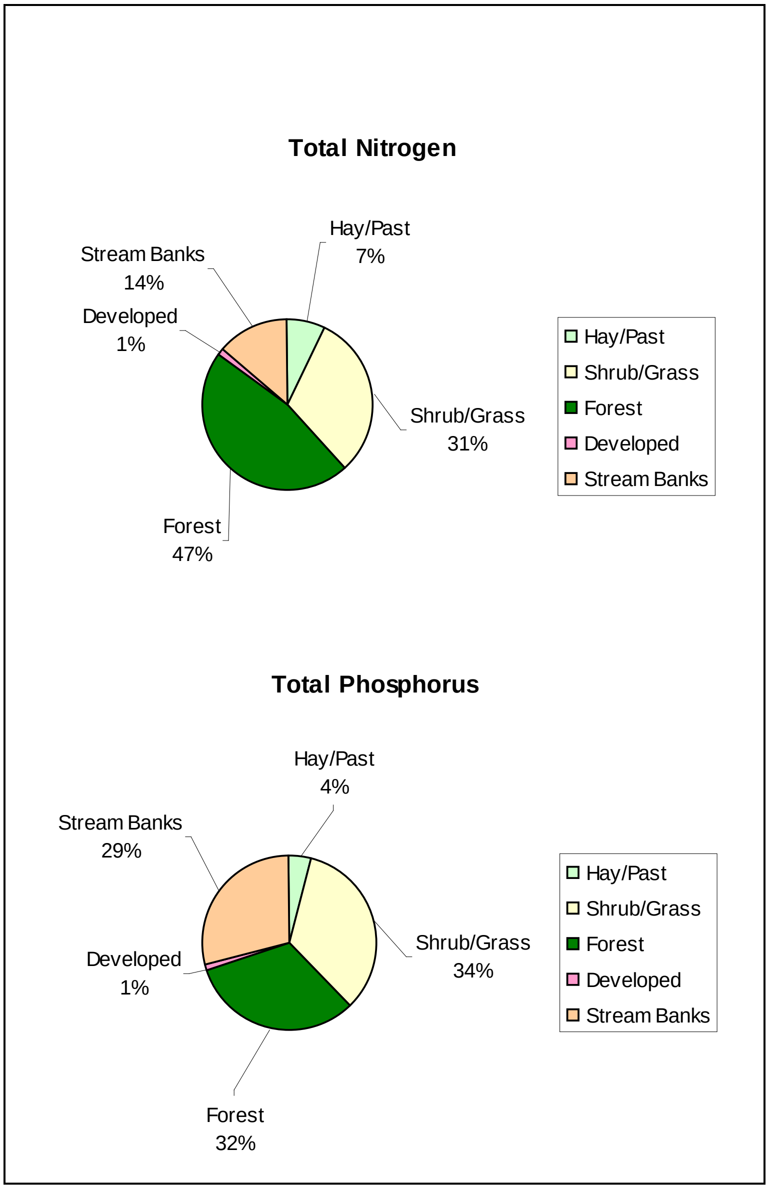


Figure 9-4: Steel Creek Nutrient Source Assessment Results

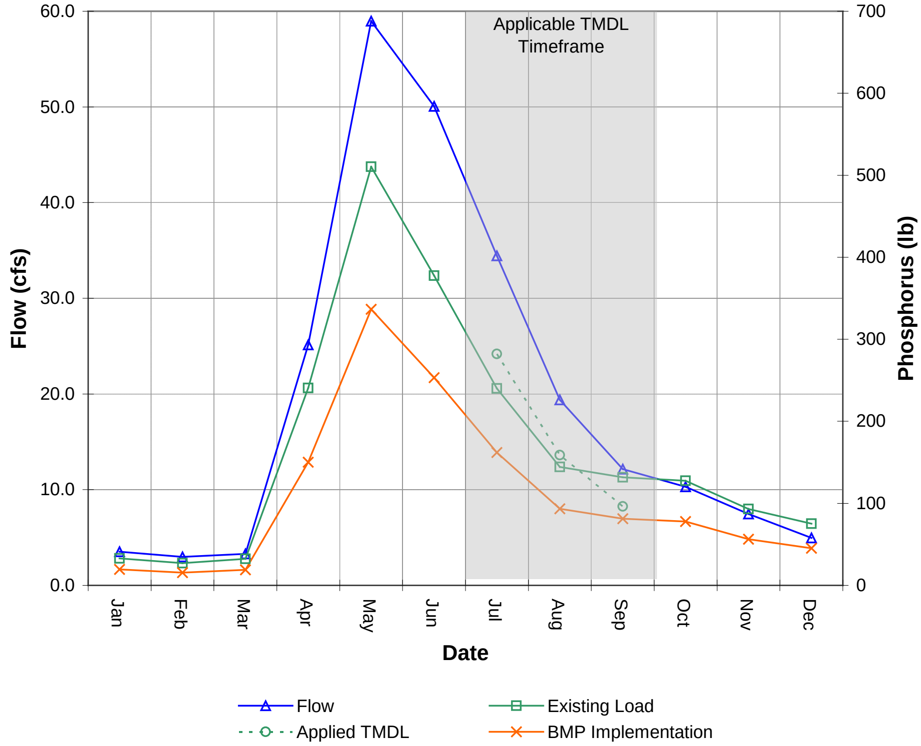
9.4.2 Steel Creek Nutrient TMDLs

Both total nitrogen and total phosphorus TMDLs will be provided for Steel Creek because the data available in this watershed is not robust and the restoration approaches in this landscape will address both nitrogen and phosphorus reductions. The total nitrogen TMDL is provided in **Equation 9-1** and the total phosphorus TMDL is provided in **Equation 9-2**. Future conditions will be considered meeting the TMDL if there is less than a 20 percent exceedance rate as long as exceedances are random during the summer months. This exceedance rate allows for natural variability yet will protect against nutrient conditions that impact any use of the water. The TMDLs are applied only to the summer growing season during July, August and September.

9.4.3 Steel Creek Nutrient Allocations

Comparison of the nutrient TMDLs to the GWLF modeling efforts provide an example of how existing and restored watershed conditions compare to the TMDL. The model estimates long term average stream flow and water quality conditions over many years. **Figure 9-5** provides an estimate of existing total nitrogen and phosphorus loads compared to the TMDLs for the calibrated hydrology in the Steel Creek Watershed. While viewing the modeling results keep in mind that modeling efforts show average flow and water quality conditions over a multiple year period and the TMDL calls for 80 percent compliance rate. Even so, comparing the modeling results of both existing and restored conditions to the TMDL is very useful because it can indicate if the restoration approaches will likely achieve the TMDL and water quality targets. While making comparisons of the TMDL and model results, keep in mind that the TMDL must be met 80 percent of the time, not approximately 50 percent of the time as **Figure 9-5** may imply because the GWLF model was built upon average conditions. To account for this difference, the TMDL allocation approach will use the results of the modeled restoration implementation scenario where all reasonable land, soil and water conservation practices are in place were the estimated median summer loads are about 1/3rd lower than the TMDL. This provides an explicit margin of safety in the TMDL and is expected to compensate for the frequency differences in the TMDL and modeling approaches.

Estimated load reductions within the GWLF model are based on agricultural restoration approaches. Reasonable agricultural restoration practices related to grazing and hay production included in the model are riparian vegetation restoration and management, fertilizer management and upland grazing management. The restoration approaches affect both nutrient production and filtering.



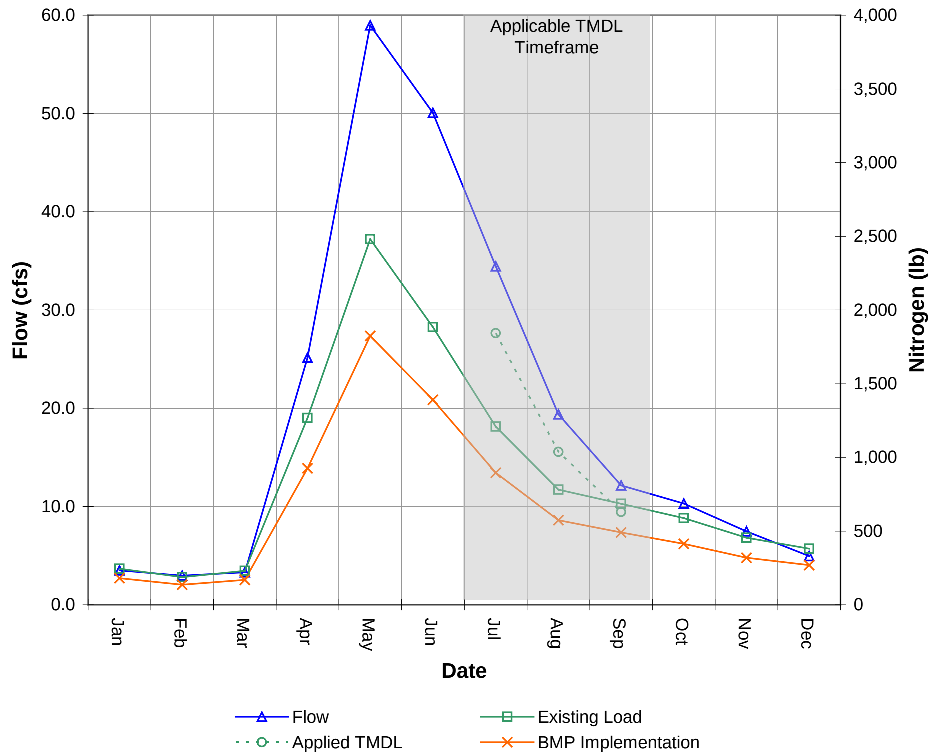


Figure 9-5: Long term average GWLF total nitrogen and phosphorus load modeling results for Steel Creek Watershed.

GWLF modeling is used to determine nitrogen and phosphorus reductions from each of the identified source reductions needed to meet the TMDL (**Appendix I**). Load reductions identified in modeling scenarios are based upon applying reasonable agricultural BMPs such as riparian vegetation restoration, riparian zone protections from grazing impacts, managing fertilizer applications rates, and moving hay production from riparian zone areas. These practices will reduce nutrients imported into the watershed, reduce bank erosion, and increase riparian filtering treatment of runoff and groundwater. Steel Creek's nitrogen and phosphorus load allocations are provided in **Table 9-4** and **9-5** respectively. Allocations are presented by source area and also by the ability of riparian areas to filter nutrients as they move toward streams. Model results of the restoration scenarios indicate that both nitrogen and phosphorus loads can be reduced the most by promoting natural riparian vegetation regrowth by managing grazing and moving hay production from these areas. Specific restoration approaches for riparian areas will depend upon how heavily impacted areas have been historically.

Allocations are provided for a yearly timeframe in the main document because the nonpoint source, landscape scale, restoration approaches will reduce nutrient conditions year round, even though the nutrient TMDL is provided only for the summer growing season. The yearly allocations will provide monthly BMP implementation loads during the summer time which are provided in **Figure 9-5.** The estimated summer monthly loads after restoration implementation are lower than the TMDL. Also, a yearly allocation approach will address sources of nutrients if they are introduced to streams during runoff but stored in channel and available during the summer growing season. All human caused significant sources are considered in the allocation approach and therefore the remaining load after implementation of restoration approaches is considered naturally occurring.

An example of the allocation approach for reducing hay and pasture nitrogen loading in Francis Creek is provided. The existing load for Hay/Pasture is 747 pounds. With fertilizer management in this source area, the existing load could be reduced by 90 lbs to 657 lbs. Of these 657 lbs, adjacent healthy stream side filter strips have the potential to reduce this load by an additional 50 percent down to 329 lbs, which is then the source area allocation to Hay/Pasture. This shows that just for this source area, the TN reduction can be greater than 50 percent with most of the reduction coming from improved riparian conditions.

Table 9-4: Steel Creek Average Annual Nitrogen Source Assessment and Restoration Load Estimation (allocation).

Source Area	Associated Human Activities	Existing Tot. N	Source Area Restoration Approach	Source Area Allocated Tot. N	Pollutant Filtering via Riparian Vegetation Improvement	Total Allocated Load From Source
		(lbs)	**(reduction in lbs)**	**(lbs)**	**(reduction in lbs)**	**(lbs)**
Hay/Past	Grazing Hay Production Fertilizer	747	Fertilizer/ Grazing Management 90	657	50% 329	329
Shrub and Grassland	Grazing	3250	Upland grazing management 151	3099	50% 1549	1549
Forest	Grazing	4834	NA	4834	0% 0.0	4834
Developed	Suburban	127	NA	127	0	127
Streambanks	Grazing Hay encroachment	1436	Riparian Vegetation restoration and grazing management 689	747	NA	747
Point Sources	Waste Load Allocation	0.0	NA	0.0	0	0
Future Sources*	All	0.0	NA	0.0	0	0
Total Estimated Annual Load		10394	931	9464	1878	7586
Estimated overall % reduction			9%		20%	27%

*If future nutrient sources occur, the allocation approach should be updated with new sources considered.

Table 9-5: Steel Creek Average Annual Phosphorus Source Assessment and Restoration Load Estimation (allocation).

Source Area	Associated Human Activities	Existing Tot. P	Source Area Restoration Approach	Source Area Allocated Tot. P	Pollutant Filtering via Riparian Vegetation Improvement	Total Allocated Load From Source
		(lbs)	(reduction in lbs)	(lbs)	(reduction in lbs)	(lbs)
Hay/Past	Grazing Hay Production Fertilizer	82	Fertilizer/Grazing Management 48.5	34	50% 17	17
Shrub and Grassland	Grazing	683	Upland grazing management 62.5	621	50% 310	310
Forest	Grazing	653	NA	653	0% 0	653
Developed	Urban	21	NA	21	0	21
Streambanks	Grazing Hay encroachment	594	Riparian Vegetation restoration and grazing management 285	309	NA	309
Point Sources	Waste Load Allocation	0	NA	0	0	0
Future Sources*	All	0	NA	0	0	0
Total Estimated Annual Load		2033	396	1637	327	1310
Estimated overall % reduction			19%		20%	36%

*If future nutrient sources occur, the allocation approach should be updated with new sources considered

9.5 Uncertainty and Adaptive Management for Nutrient TMDLs

An adaptive management strategy is proposed to facilitate revision of the nutrient targets, TMDLs, and allocations for Steel and Francis Creek. Although there is uncertainty in the loading values and relative contributions, there is a relatively high level of certainty that the land use practices that can be addressed via the identified BMPs will provide the largest reductions in nutrient loading. This is supported by the modeling, review of literature, overall source assessment results and field observations.

Future nutrient and stream flow monitoring should occur in these streams to better characterize nutrient, discharge and water use conditions. The allocation approach is supported by GWLF modeling that was calibrated at the Big Hole Watershed scale. As new monitoring results applicable to each TMDL are attained they should be compared to the water quality targets, TMDLs and modeling results. If monitoring results do not fall in line with the allocation approach, new allocation approaches which match specific data from the watershed should be considered.

There are two primary regulatory mechanisms through which water quality targets and TMDLs may be modified in the future, as follows: (1) Montana Code Annotated 75-5-703(9)(c) provides a provision for revising the TMDL based on an evaluation conducted by DEQ five years after the TMDL is completed and approved and (2) DEQ has begun the initial steps of numeric standards development for nutrients. DEQ expects to start the formal rule making process for adoption of numeric standards within the next two years. Prior to the start of formal rulemaking, DEQ will provide opportunity for informal public comment, as well as for the formal public comment prescribed under statute. If Montana initiates the use of numeric nutrient criteria, these criteria may be used to revise the nutrient TMDLs provided in this document during future TMDL review. It is envisioned that the additional data collection and regulatory elements together will provide the needed data and information to revise the proposed interim nutrient targets, TMDLs and allocations.

9.6 Margin of Safety and Seasonal Considerations for Nutrient TMDLs

The nutrient margin of safety is inherently provided in conservative assumptions during the source assessment and BMP implementation modeling scenarios. The nutrient reduction BMP modeling scenarios indicate BMP implementation is likely achieve nutrient reductions lower than the TMDLs. The allocation approach is built upon the modeled BMP scenarios. Additionally, nutrient filtering efficiency by riparian areas was estimated on the low end of ranges that were investigated and existing conditions of riparian zones were also accounted for during the filtering capacity improvement portion of the nutrient reduction assessment. A moderate condition was used for the restorative conditions of upland cover in grazed landscapes. Fertilizer application rates used for the fertilizer management scenario were those that began to be applied during 2008 because of fertilizer cost increases. The allocations are built upon restoration scenarios that are reasonably achievable. These allocations are estimated to meet the TMDLs and protect all uses from nutrient enrichment. The adaptive management approach provided in **Section 9.5** also provides a feedback loop to address uncertainties.

The nutrient targets and TMDLs are provided to protect against nuisance algae growth during the summer and apply only during this timeframe. Allocations are provided for year round conditions to ensure summer timeframe targets are met. Modeling results indicate that targets and TMDLs are achieved during summer via the restoration and allocation approach which is based upon protecting riparian filtering zones, reducing fertilizer application rates, and increasing upland vegetation cover year round. Nonpoint source restoration approaches provided in **Section 10.0** should reduce nutrient concentrations and loads during all seasons. The allocation approach, which applies to all seasons, is also consistent in protecting downstream uses in nutrient impacted reservoirs downstream of this TPA.

SECTION 10.0
FRAMEWORK FOR WATER QUALITY RESTORATION

10.1 Summary of Upper Big Hole Restoration Strategy:

This section provides a framework strategy for water quality restoration in the Upper Big Hole Valley and surrounding mountains, focusing on how to meet conditions that will likely achieve the TMDLs presented in this document. This section identifies which activities will contribute the most reduction in pollutants for each TMDL. Limited information about spatial application of each restoration activity will be provided.

This section should assist stakeholders in developing a more detailed adaptive Watershed Restoration Plan (WRP) in the future. The locally developed Watershed Restoration Plan will likely provide more detailed information about restoration goals and spatial considerations within the watershed. The WRP may also encompass more broad goals than this framework water quality restoration plan focuses upon. The to-be-developed WRP would serve as a locally organized "road map" for watershed activities, sequences of projects, prioritizing types of projects, and funding sources, towards achieving local watershed goals, including water quality improvements. Within this plan, the local stakeholders would identify and prioritize streams, tasks, resources, and schedules for applying Best Management Practices (BMPs). As restoration experiences and results are assessed through watershed monitoring, this strategy could be adapted and revised by stakeholders based on new information and ongoing improvements.

10.1.2 Links Between Fishery and Water Quality Restoration

Many of the restoration strategies in this section fall in line with another important watershed conservation effort, the Candidate Conservation Agreement with Assurances (CCAA) (USFWS and MFWP, 2006). The CCAA agreement between MFWP and the US Fish and Wildlife Service affords private landowners who implement specified conservation practices on their lands protection from additional regulations in the event that the Arctic grayling would receive protection under the Endangered Species Act (ESA). In the Upper Big Hole, the majority of the Arctic grayling priority habitat areas are located on private lands, generally in the valley areas. Final goals of TMDL and CCAA efforts may differ, but the two processes are linked. Water quality laws in Montana are set to protect all beneficial uses of a stream, with fish and aquatic life being some of the most sensitive. TMDLs are provided to protect all uses, including grayling, against adverse conditions that increased pollutant loads may cause.

The CCAA specifies a series of key restoration actions for stream areas supporting Arctic grayling, including maintenance of clean water flows and riparian/stream restoration. In addition, the CCAA assigns agency and landowner responsibilities for implementation of conservation activities and provides extensive landowner participation. These CCAA elements facilitate implementation of restoration activities conserving Arctic grayling populations, as well as supporting beneficial water uses. Many of the CCAA fishery restoration activities will overlap with restoration activities outlined in this document, especially riparian habitat improvement, bank erosion restoration, stream channel stability, and stream flow improvements. Spatial consideration for implementation of CCAA fishery projects and TMDL water quality improvement restoration guidance may overlap at times, but each process also has independent spatial goals. Coordination of restoration activities between CCAA fishery restoration activities and TMDL water quality restoration activities should be coordinated.

10.2 Watershed Restoration Goals

The following are general water quality goals provided in this TMDL document:

- Provide technical guidance for full recovery of aquatic life beneficial uses to all impaired streams within the Upper and North Fork Big Hole TMDL Planning Areas (TPAs) by improving sediment, nutrient, and temperature water quality conditions. This technical guidance is provided by the TMDL components in the document.
- Identify a framework watershed restoration approach for water quality restoration activities that will attain sediment, temperature, and nutrient water quality standards in waters with TMDLs.
- Assess watershed restoration activities to address significant pollutant sources. Costs and benefits are both generally considered, although this analysis does not use a detailed cost/benefit analysis. General spatial guidance will be provided for restoration activities.

A Watershed Restoration Plan (WRP) is a locally derived plan that can be more dynamic than the TMDL document. It can be refined as activities progress and address more broad goals than those included in this TMDL document. The following may be elements provided in a stakeholder derived Watershed Restoration Plan (WRP) in the near future:

- Support for implementing Best Management Practices (BMPs) to protect water conditions so that all streams in the watershed maintain good water quality with an emphasis on waters with TMDLs completed.
- More detailed cost/benefit and spatial considerations for water quality improvement projects.
- Develop an approach for future BMP installments and efficiency results tracking.
- Provide information and education components for providing stakeholder outreach about restoration approaches, benefits, and funding assistance.
- Other various watershed health goals may be included.

Specific water quality goals are detailed in **Section 4** of this document. These targets serve as the basis for long-term effectiveness monitoring for achieving the above water quality goals (**Section 11**). These targets specify satisfactory conditions to ensure protection and/or recovery of beneficial uses of Big Hole waters. **Section 11** identifies a general approach to the monitoring recommendations designed to track implementation water quality conditions and restoration successes.

10.3 Framework Watershed Management Recommendations

Sediment TMDLs were completed for 18 watersheds, including the upper Big Hole River. The Big Hole River was addressed with a temperature TMDL, and nutrient TMDLs were completed for Francis and Steel Creeks. The **most important** restoration approach for reducing sediment, thermal, and nutrient loading in the upper Big Hole Valley is streamside riparian restoration and long term riparian zone management. Stream channel restoration may be necessary in areas that have lost channel integrity due to long term riparian vegetation impacts. Other sediment restoration actions would include unpaved road erosion control near streams. The most notable nutrient specific restoration approach, besides streamside riparian vegetation restoration, includes fertilizer and irrigation management. Temperature TMDL attainment will depend upon improving stream shade using increased riparian vegetation, stream channel narrowing/deepening, and irrigation and stockwater conservation management on both the upper Big Hole River and significant tributaries.

10.3.1 Sediment Restoration Approaches

Streamside riparian vegetation restoration and long term riparian area management are vital restoration practices that must be implemented across the watershed to achieve the sediment TMDLs. Vigorous native streamside riparian vegetation provides root mass which hold streambanks together. Suitable root mass density ultimately slows bank erosion. Riparian vegetation filters sediment from upland runoff. Sediment is also deposited more heavily in healthy riparian zones during flooding because water velocities slow in these areas and sediment drops from the stream's water.

Most of the sediment TMDLs identify eroding banks as the largest human influenced sediment source (**Table 10-1**). Riparian vegetation restoration will address this source, along with channel restoration, that may be necessary in heavily impacted stream reaches where channel stability has been compromised by long term riparian vegetation impacts. The predominant cause of riparian and stream channel degradation in the upper Big Hole Watershed comes from grazing of domesticated livestock in and near streams. Hay production encroaching into riparian zones also impacts riparian vegetation condition in numerous areas. **Table 10-1** provides a summary of load reductions along with ranked sources and possible Best Management Practices (BMP) associated with each source. The table also identifies general spatial guidance for each watershed with a sediment TMDL. Also see **Appendix K**, **Map 4** for spatial considerations when considering riparian vegetation improvement projects.

Erosion off of uplands was usually the second most predominant human influenced source of sediment in the TMDLs provided. The restoration approach for this source will be to increase streamside riparian area sediment filtering capacity by restoring streamside vegetation zones. This approach reinforces the idea that riparian vegetation restoration and long term riparian zone vegetation management should be the predominant restoration approach to reduce sediment.

On average, erosion off of unpaved roads fell next in line of controllable sediment sources in the upper Big Hole Watershed. Restoration approaches for unpaved roads near streams should be to divert water off of roads and 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. Sediment derived from roads may cause significant localized impact in some stream reaches, even though at a watershed scale it may be a moderate or small source. Sediment loads from culvert failure and culvert caused scour were not assessed by the TMDL source assessment, but should be considered in road sediment restoration approaches.

All of these best management practices are considered reasonable restoration approaches due to their benefit and generally low costs. Riparian restoration and road erosion control are standard best management practices identified by NRCS and are not overly expensive to our society. Many riparian areas could benefit from more active grazing management along with some additional fencing costs and would recover naturally. Active vegetation planting along with bank sloping may increase costs, but still remains within a reasonable and relatively cost effective restoration approach. When stream channel restoration work is needed because of altered stream channels, costs increase and projects should be assessed on a case by case basis.

Historic placer mining activities may have very localized impacts that affect sediment production within the watershed. Large scale placer mining was not a predominant or common practice in this area when compared to most other areas of southwest Montana. If found, mining caused sediment sources that can be restored at reasonable costs could be prioritized into the watershed restoration plan. Any other unknown sediment sources could also be incorporated into the watershed restoration plan while considering cost and sediment reduction benefits.

For the whole upper Big Hole Watershed, sediment load reductions identified in this TMDL document are allocated from eroding banks (81 percent), grazing/hay lands (17 percent) and roads (2 percent). Past human influences, such as channel and flow alteration, and mining, also have contributed locally notable increases in sediment production. These human caused activities contribute to instream sediment loads which average 31 percent above levels achieving water quality targets. Current estimated watershed sediment loads total 141,976 tons annually, with this TMDL targeting a total watershed load reduction of 44,013 tons annually from the whole watershed. Through application of locally appropriate Best Management Practices, sediment loads in individual streams can be reduced between 12 and 46 percent (**Table 10-1**).

Table 10-1: Summary of Sediment Load Reductions and Ranked Restoration Strategy by watershed

Name of Water body	Current Sediment Loads (tons per year)	TMDL Sediment Load Reduction (% of total load)	Source and Restoration Rank	Ranked Controllable Sources	Ranked BMP Type	Spatial concerns
Big Hole River -above Pintlar Creek	141,976	31%	1	Eroding Banks needing sustainable riparian zone vegetative condition	Riparian grazing management, Riparian willow vegetation restoration, Move haying from riparian green line	Eroding banks with insufficient riparian cover occur along significant but intermittent reaches of the Big Hole River. Some riparian areas are managed well and others need riparian restoration work. Tributaries should also be addressed to reduce sediment loads to the Big Hole River. See TMDLs and restoration summaries below for tributary information.
			2	Upland Sediment,	See eroding banks (above) restoration approach which also provide vegetation filter zones along streams	Riparian filtering capacity is highly variable along reaches of the Big Hole river. Tributary riparian filtering capacity should also be addressed. See TMDL water body summaries below for tributaries.
			3	Unpaved roads	Road maintenance and runoff BMPS	Road maintenance should occur on many unpaved road crossings. Spatial considerations are provided in Appendix G.
Doolittle Creek	1,292	26%	1	Eroding Banks needing sustainable riparian zone vegetative condition	Riparian grazing management, Riparian willow vegetation restoration,	Grazing improvements should continue in the mid section of Doolittle Creek, below Beaverhead Deerlodge National Forest boundary. Many areas need more time to revegetate and recover from past streamside grazing activities but currently have improved grazing management and are recovering.
			2	Upland Sediment from grazing	Riparian grazing management, Provide vegetation filter zones along streams	

Table 10-1: Summary of Sediment Load Reductions and Ranked Restoration Strategy by watershed

Name of Water body	Current Sediment Loads (tons per year)	TMDL Sediment Load Reduction (% of total load)	Source and Restoration Rank	Ranked Controllable Sources	Ranked BMP Type	Spatial concerns
Fox Creek	2,759	41%	1	Eroding Banks needing sustainable riparian zone vegetative condition	Riparian grazing management, Riparian willow vegetation restoration, Move haying from riparian green line	Improvements could be achieved in tributaries and upper Fox Creek but riparian management appears to be fair to good along the mid/lower mainstem. There may also be some effects from irrigation infrastructure. Much of grazing effects occur on public lands.
			2	Upland Sediment from grazing	Riparian grazing management, Provide filter strips along streams	
Francis Creek	2,279	23%	1	Eroding Banks needing sustainable riparian zone vegetative condition	Stream side riparian vegetation restoration Riparian grazing management, Riparian willow vegetation restoration,	The whole stream needs much more attention devoted to riparian management and promoting shrub species growth along streambanks. Many areas may need active vegetation restoration and channel restoration work completed. Moderate to high livestock impacts to upland vegetation in some areas. Spatial considerations for roads are provided in Appendix G.
			2	Upland Sediment from grazing	Riparian grazing management, Provide filter strips along streams	
			3	Unpaved roads	Road maintenance and runoff BMPS	

Table 10-1: Summary of Sediment Load Reductions and Ranked Restoration Strategy by watershed

Name of Water body	Current Sediment Loads (tons per year)	TMDL Sediment Load Reduction (% of total load)	Source and Restoration Rank	Ranked Controllable Sources	Ranked BMP Type	Spatial concerns
Governor Creek	25,646	41%	1	Eroding Banks needing sustainable riparian zone vegetative condition	Riparian grazing management, Stream side riparian vegetation restoration Riparian willow vegetation restoration,	Intermittent portions of the stream need more attention devoted to riparian management. Inappropriate channel restoration design may have occurred in one reach. Moderate to high livestock impacts to upland vegetation in some areas. Spatial considerations for road system are provided in Appendix G.
			2	Upland Sediment from grazing	Riparian grazing management, Provide filter strips along streams	
			3	Unpaved roads	Road maintenance and runoff BMPS	
Johnson Creek	2,432	18%	1	Eroding Banks needing sustainable riparian zone vegetative condition	Riparian grazing management, Stream side riparian vegetation restoration,	In general, below the USFS boundary, streamside vegetation is in moderate condition with limited areas of both good and poor conditions. The whole portion of this stream in the North Fork Big Hole River valley would benefit from slight improvements in grazing management. Current grazing management is not bad in most areas, but less riparian brose at ground level from livestock is needed.
			2	Upland Sediment from grazing	Riparian grazing management, Provide filter strips along streams	
Joseph Creek	990	19%	1	Eroding Banks needing sustainable riparian zone vegetative condition	Stream side riparian vegetation restoration Riparian grazing management, Riparian willow vegetation restoration,	Very little can be done to improve streamside vegetation. Natural conditions, beaver, sandy geology, and hydrologic impacts of the highway all may impact bank erosion. Historic human caused sediment loads may still be present in the channel. Road sanding BMPs should occur due to localized impacts even though they are a small load.

Table 10-1: Summary of Sediment Load Reductions and Ranked Restoration Strategy by watershed

Name of Water body	Current Sediment Loads (tons per year)	TMDL Sediment Load Reduction (% of total load)	Source and Restoration Rank	Ranked Controllable Sources	Ranked BMP Type	Spatial concerns
McVey Creek	1,754	31%	1	Eroding Banks needing sustainable riparian zone vegetative condition	Stream side riparian vegetation restoration Riparian grazing management, Riparian willow vegetation restoration,	Most of the non Beaverhead Deerlodge National Forest land needs more attention applied to riparian grazing management. State lands are most poorly managed. Active riparian restoration may be needed in specific areas. Channel restoration may be needed in places.
			2	Upland Sediment from grazing	Riparian grazing management, Provide filter strips along streams	
Miner Creek	3,698	17%	1	Upland Sediment from grazing	Riparian grazing management, Provide filter strips along streams	Riparian areas are generally in good condition but there are limited sections of the stream that could benefit from riparian restoration. Road system should be looked at closely for BMP implementation. There are limited areas in need of restoration projects in this watershed.
Mussigbrod Creek	2,134	14%	1	Eroding Banks needing sustainable riparian zone vegetative condition	Stream side riparian vegetation restoration Riparian grazing management, Riparian willow vegetation restoration,	The whole portion of this stream in the North Fork Big Hole River valley would benefit from slight improvements in grazing management. Current grazing management is not bad, but less riparian brose at ground level from livestock is needed.
			2	Upland Sediment from grazing	Riparian grazing management, Provide filter strips along streams	

Table 10-1: Summary of Sediment Load Reductions and Ranked Restoration Strategy by watershed

Name of Water body	Current Sediment Loads (tons per year)	TMDL Sediment Load Reduction (% of total load)	Source and Restoration Rank	Ranked Controllable Sources	Ranked BMP Type	Spatial concerns
North Fork Big Hole River	28,642	20%	1	Eroding Banks needing sustainable riparian zone vegetative condition	Riparian grazing management, Stream side riparian vegetation restoration Riparian willow vegetation restoration,	Generally riparian grazing management improves in an upstream direction. Loss of riparian shrubs is evident in a downstream direction. Bank erosion increases from upstream to downstream. Many areas will need active riparian restoration approaches due to lar. Spatial considerations for road system are provided in Appendix G.
			2	Upland Sediment from grazing	Riparian grazing management, Provide filter strips along streams	
			3	Unpaved and paved roads	Road maintenance and runoff BMPS	
Pine Creek	961	46%	1	Eroding Banks needing sustainable riparian zone vegetative condition	Stream side riparian vegetation restoration Riparian grazing management, Riparian willow vegetation restoration	Sediment loads would be reduced by grazing management practices that promote willow regeneration. This stream could recover naturally if riparian zones were rested and subsequently grazed periodically to lessen browse.
			2	Upland Sediment from grazing	Riparian grazing management, Provide filter strips along streams	

Table 10-1: Summary of Sediment Load Reductions and Ranked Restoration Strategy by watershed

Name of Water body	Current Sediment Loads (tons per year)	TMDL Sediment Load Reduction (% of total load)	Source and Restoration Rank	Ranked Controllable Sources	Ranked BMP Type	Spatial concerns
Rock Creek	7,084	31%	1	Eroding Banks needing sustainable riparian zone vegetative condition	Riparian grazing management, Stream side riparian vegetation restoration Riparian willow vegetation restoration,	Most of the portions of this stream in the Upper Big Hole Valley appeared to need a rest from riparian area riparian grazing and subsequent long term grazing management that allows riparian shrubs to grow. Many areas of this stream may need active riparian restoration work. Some areas may need channel restoration work if a deep, narrow channel is wanted in a short timeframe. Spatial considerations for road system are provided in Appendix G.
			2	Upland Sediment from grazing	Riparian grazing management, Provide filter strips along streams	
			3	Unpaved and paved roads	Road maintenance and runoff BMPS	
Ruby Creek	4,791	10%	1	Eroding Banks needing sustainable riparian zone vegetative condition	Riparian grazing management, Stream side riparian vegetation restoration,	Riparian areas are generally in moderate to good condition but there are limited sections of the stream that could benefit from riparian grazing management. Active vegetation or channel restoration approaches other than fencing are likely not needed. Road system should be looked at closely for BMP implementation.
			2	Upland Sediment from grazing	Riparian grazing management, Provide filter strips along streams	
Steel Creek	8,081	34%	1	Eroding Banks needing sustainable riparian zone vegetative condition	Stream side riparian vegetation restoration Riparian grazing management, Riparian willow vegetation restoration,	All non Beaverhead Deerlodge National Forest areas need more attention devoted to riparian management and promoting sufficient shrub species condition along streambanks. Many areas may need active vegetation restoration along with channel restoration work. Very limited areas of the BHNF may need riparian grazing management improved slightly.
			2	Upland Sediment from grazing	Riparian grazing management, Provide filter strips along streams	

Table 10-1: Summary of Sediment Load Reductions and Ranked Restoration Strategy by watershed

Name of Water body	Current Sediment Loads (tons per year)	TMDL Sediment Load Reduction (% of total load)	Source and Restoration Rank	Ranked Controllable Sources	Ranked BMP Type	Spatial concerns
Swamp Creek	5,824	27%	1	Eroding Banks needing sustainable riparian zone vegetative condition	Stream side riparian vegetation restoration Riparian grazing management, Riparian willow vegetation restoration,	Generally riparian grazing management should be conducted to improve streamside shrub growth throughout the Big Hole Valley portions of this stream. Many areas may need active restoration approaches in the lower reaches of this stream.
			2	Upland Sediment from grazing	Riparian grazing management, Provide filter strips along streams	
Tie Creek	1,771	18%	1	Upland Sediment from grazing	Riparian grazing management, Provide filter strips along streams	Portions of Lower Tie Creek could use moderate improvements in riparian grazing management.
			2	Eroding Banks needing sustainable riparian zone vegetative condition	Stream side riparian vegetation restoration Riparian grazing management, Riparian willow vegetation restoration,	
Trail Creek (upper – above Joseph Cr.)	2,015	20%	1	Eroding Banks needing sustainable riparian zone vegetative condition	Stream side riparian vegetation restoration Riparian grazing management, Riparian willow vegetation restoration,	Portions of the eroding banks may be tied to increased water yield due to fires as well as direct impact from fire. Low riparian cover may also be linked to fire. Some of the eroding banks are remnant of past livestock grazing but are healing.

Table 10-1: Summary of Sediment Load Reductions and Ranked Restoration Strategy by watershed

Name of Water body	Current Sediment Loads (tons per year)	TMDL Sediment Load Reduction (% of total load)	Source and Restoration Rank	Ranked Controllable Sources	Ranked BMP Type	Spatial concerns
Trail Creek (lower)	5,395	12%	1	Eroding Banks needing sustainable riparian zone vegetative condition	Riparian grazing management, Stream side riparian vegetation restoration Riparian willow vegetation restoration,	Portions of Lower Tie Creek could use slight to moderate improvements in riparian grazing management. A portion of the bank erosion may be caused by historic channel alterations from the highway as well as historic grazing impacts. Many riparian areas are recovering from historic impacts.
			2	Upland Sediment from grazing	Riparian grazing management, Provide filter strips along streams	
			3	Unpaved roads	Road maintenance and runoff BMPS	
Warm Springs Creek	NA	NA	1	Eroding Banks needing sustainable riparian zone vegetative condition	Riparian grazing management, Stream side riparian vegetation restoration Riparian willow vegetation restoration,	Intermittent areas of Warm Springs Creek could benefit from riparian grazing management to increase riparian willows. Near Jackson, haying activities should provide a streamside buffer witch will allow willows to grow on banks.
			2	Upland Sediment from grazing	Riparian grazing management, Provide filter strips along streams	

10.3.1.1 Big Hole River and North Fork Big Hole River

Because of the differential response of the Big Hole River and the North Fork Big Hole River to reduce shrub cover, namely markedly increased width-to-depth ratio, these streams require different restoration approaches to achieve targets and allocations in a timely manner. The role of these streams in providing substantial habitat for Arctic grayling justifies a more intensive approach to meeting targets for the most-altered reaches. Three types of reaches were delineated in the aerial photo based riparian assessment and were linked to increased width-to-depth ratios and bank erosion (**Appendix K**, **Map 4**):

- Sparsely vegetated C channels (defined as less than 20 percent shrub cover) with a potential to be DA, C, or E channels with dense shrub cover (defined as greater than 35 percent shrub cover).
- Reaches with moderate shrub cover with a potential for dense shrub cover, and
- Reaches meeting their potential for dense shrub cover.

Restoration strategies for these three classes vary from a most-aggressive approach involving significant channel work to simple continuance of existing BMPs (**Table 10-1**)

10.3.1.2 Big Hole River Tributaries

Most tributary streams do not show the marked alterations in width-to-depth ratio with low shrub cover; therefore, primarily less intensive restoration options would apply to the tributary streams. A first restoration strategy is to stratify between Rosgen defined “B channels” and other channel types on tributaries (mostly Rosgen Cs, Es, and Das). The rationale is that coniferous forest dominated “B” channels do not have the potential to provide robust habitat for willows. Therefore, the Rosgen “B” channel stream reaches have notably different vegetative potential.

These Rosgen stream type Cs, Ds, and Es, (non-B tributaries) were classified as to their existing and potential shrub cover. Stream reaches with existing dense shrub cover and meeting their potential have a restoration strategy to continue implementing existing BMPs. Non-B tributary reaches having sparse shrub cover and a potential for dense shrubs should involve a combination of willow sprigging and grazing BMPs in most areas. Steel, Francis, and lower portions of Rock and Swamp creeks are notably different from the other tributaries due to the severity of eroding banks, lack of riparian vegetation, and high width-to-depth ratio. The condition of these streams necessitates a much more aggressive restoration approach than what is proposed for the other tributary streams (**Table 10-1**).

10.3.2 Nutrient Restoration Approaches

Nutrient TMDLs were developed for Francis and Steel Creeks using a nutrient model and land use information. Francis Creek is a tributary to Steel Creek, and both watersheds exhibited similar nutrient source assessment results. Nutrient source assessment results are provided by land use type as well as for eroding banks.

The largest nitrogen and phosphorus loads came from forested areas. Nutrient loading from upland forest areas is almost entirely natural in both watersheds. Only a small portion of forest land derived nutrient loads could be further removed by increasing adjacent riparian streamside vegetation vigor. Slight nutrient reductions could occur from forest nutrient loads at the watershed scale by restoring all adjacent streamside vegetation to reference conditions because most riparian areas adjacent to a forest are relatively healthy.

Upland dry shrub and grassland used for domestic livestock grazing contributes the next largest load of nitrogen and phosphorus. If upland grazing management could increase vegetation cover in these areas by 18 percent, watershed nitrogen and phosphorus loads would decrease by about 1 percent and 4 percent respectively. Alternatively, if streamside riparian conditions on the whole stream network adjacent to dry shrub and grasslands were managed similar to reference areas in the Big Hole Watershed, nitrogen and phosphorous loads at the watershed scale would be reduced by 14-16 percent depending upon the watershed and nutrient type.

Bank erosion is a significant source of nutrients in Francis and Steel creeks. Much more phosphorus than nitrogen is contributed from eroding banks when assessing the percentage of contribution eroding banks provide to the overall watershed load. Riparian vegetation restoration and management once again provide the avenue for increasing root mass in banks which reduces bank erosion and the associated nutrient loads. Reducing bank erosion to reference conditions will reduce nitrogen and phosphorus loads at the watershed scale by approximately 4 percent and 8 percent respectively in both watersheds.

Irrigated hay and pasture land is another controllable source. Fertilizers are used in these areas in conjunction with irrigation networks and together contribute nutrient loads to stream networks. Upland vegetation cover may also be impacted in these areas, and through active management, could reduce nutrient production. Nutrient loads from these areas are estimated as low when compared to other land types at the watershed scale, although the model likely underestimated hay and pasture land areas in the watershed. Nutrient loads from pasture and hay were quite high if normalized by area (on a pre acre basis). On-farm nutrient management should be pursued as a nutrient reducing restoration approach. Activities on hay and pasture land that may promote less nutrient reaching the stream network include irrigation management, fertilizer management, and manure management practices. Addressing adjacent riparian filtering function should once again be the priority restoration approach to reducing nutrient loads from irrigated pasture and hay fields. Also included in this category are Animal Feeding Operation areas (AFOs) that should be addressed via installing drainage routes away from streams and installing buffer zones along streams. If the preceding approaches are not feasible approaches, moving an AFO away from the stream may be necessary.

Stream side riparian vegetation restoration approaches are identified as the best way to mitigate nutrient loading to Francis and Steel Creek and should be top priority for restoration projects that will reduce nutrient loads. Other restoration activities that can be pursued are on-field nutrient management strategies (fertilizer and irrigation management) and upland grazing management to promote more vegetation cover. The TMDLs have the potential to be achieved via streamside riparian vegetation restoration approaches without the other two sources being considered; although, a monitoring and adaptive management approach would need to be considered if riparian vegetation restoration and management was the only restoration activity applied to these watersheds. Alternatively, on-farm nutrient management should be seriously considered because it may save overhead cost without affecting production and it will also benefit the environment.

10.3.3 Temperature Restoration Approaches

A temperature TMDL was developed for the Upper Big Hole River by means of a temperature model which utilized water temperature, stream flow, and streamside vegetation data. The approach for attainment of temperature targets is based upon reaching stream channel and streamside vegetation conditions equaling reference areas. Another very important restoration factor for meeting temperature conditions that support instream uses depends upon irrigation and stock water management with water savings being applied to instream flow during warm summer months. The two largest influences upon temperature of the Upper Big Hole River are the lack of riparian vegetation for shade and low summer time stream flow. The overly wide and less complex stream channel also is a significant contributor to heating, but estimated as less than the other influences.

Riparian grazing management, which promotes native shrub growth along streambanks to reference area levels, is a necessary restoration component for meeting the Big Hole River temperature TMDL. Increasing shrub density along streambanks that are not dominated by conifers is needed along the Upper Big Hole River and all impacted tributaries. The climax riparian condition is shrub dominated because cottonwood trees do not grow in the upper Big Hole Watershed because of the harsh climate. Conifer harvest within 300 ft of streams should demonstrate that stream shade is not significantly impacted. The riparian shrubs increase shade and promote cooler microclimates near the streams. Although the increased riparian vegetation may increase evapotranspiration in riparian areas, they are a very small percentage of the watershed area. Cooler temperatures in and near the stream will promote less evaporation from the stream surface itself. Restoring riparian shade, via vegetation growth, also falls in line with restoration approaches linked to sediment and nutrient reductions. Restoring natural riparian vegetation communities dominated by shrubs is a key element in reducing all pollutant loads including heat.

Irrigation efficiency projects which promote summer time instream flows should be considered as another primary restoration approach to reducing temperatures in the upper Big Hole River. Although no exact flow target is provided, modeling indicated that a 10cfs increase in flow would significantly cool stream water. All reasonable irrigation savings approaches with water savings applied to instream flows during July, August and early September should be pursued. This would have to be a locally lead, voluntary effort. Voluntary landowner, ditch company, DNRC, and FWP participation is necessary to obtain this goal. There is no regulatory authority to implement this objective. State law indicates that legally obtained water rights cannot be divested, impaired, or diminished by Montana's water quality law (MCA 75-5-705); therefore, local coordination and planning are a necessary component of any irrigation management strategy. This document can not be used to divest water rights.

Over wide and shallow channels create conditions where heat can transfer to the streams more efficiently during hot summer afternoons. Reducing the width and increasing the depth of streams in the upper Big Hole Watershed ties into riparian vegetation restoration approaches. Many streams, including many portions of the Big Hole River, have been widened due to streamside shrub loss and subsequent bank erosion. Over a long term period, the sediment from the banks falls into the stream and larger sized cobbles can not be moved easily. These fill in the stream bottom and the process over-widens the stream. In some cases, protecting riparian vegetation so that it can naturally restore itself will promote deeper and narrower channels over time because the stream will create a new floodplain where sediments are trapped and the stream narrows from passive vegetation regrowth. Alternatively, in many areas channel restoration may be needed to change channel dimensions at a faster pace than passive restoration approaches provide. Riparian livestock grazing management must be a component of any active riparian or channel restoration projects to ensure the projects are successful.

10.4 Restoration Approaches by Source

General management recommendations are outlined below for the major sources of human caused pollutant loads in the Upper Big Hole watershed (grazing -including streambank/riparian disturbances, irrigation, and nutrients). Applying ongoing Best Management Practices (BMPs) are the core of the sediment reduction strategy, but are only part of the 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 sediment sources. In these cases, BMPs are usually identified as a first effort, and an adaptive management approach will be used to determine if further restoration approaches are necessary to achieve water quality standards. Monitoring is also an important part of the restoration process. Monitoring recommendations are outlined in **Section 11**.

A wide variety of grazing management, riparian restoration, fencing, nutrient management, stockwater efficiency, irrigation efficiency, and other watershed restoration improvements have been implemented in recent years in many parts of the Upper Big Hole watershed, particularly under the Big Hole “Candidate Conservation Agreement with Assurances” (CCAA) for fluvial Arctic grayling in the upper Big Hole area.. The CCAA restoration efforts focus on improving fishery habitat (water quantity and riparian habitat), water quality (thermal and nutrient management), and fish habitat fragmentation (dewatering, barriers to migration, entrainment, and habitat simplification).

10.4.1 General Grazing Management BMP Recommendations

Improving riparian habitat, streambank erosion and channel condition through grazing BMPs are documented in the literature (Mosley et al., 1997). The restoration strategy for reducing impacts of grazing on water quality and riparian and channel condition includes implementation of multiple BMPs prescribed on a site-specific basis (such as through the CCAA landowner agreements). BMPs are most effective as part of a management strategy that focuses on critical areas within the watershed, i.e. those areas contributing the largest pollutant loads or sites which are susceptible to impacts from grazing. These riparian BMPs promote properly functioning riparian communities and reduce damage to streambanks. BMPs include managing the timing, intensity, and duration of grazing, establishment and maintenance of preferred vegetative cover, development of infrastructure such as fences and hardened crossings, and management of feeding areas, salt licks, and water availability to restore and maintain riparian vegetation and streambanks. In combination, these integrated approaches to riparian management promote vegetative vigor and protects near-stream soils. BMPs should be determined on a site-specific basis that incorporates the landowner’s production needs and associated logistics, while promoting attainment of sediment/riparian allocations and targets.

Some general grazing management recommendations, and BMPs to address grazing sources of pollutants and pollution are listed below (**Table 10-2**). Specific recommendations for critical areas and streams are described in **Sections 10.2** (CCAA and recent BMPS), and **Section 10.3** (stream-specific BMPs).

For participants in the CCAA program, the MFWP and NRCS are developing grazing management plans with enrolled landowners agreeing to implement these measures to meet riparian targets. On lands not enrolled in the CCAA, implementation of BMPs is voluntary. However, other planning partners, including the Big Hole Watershed Committee and the NRCS, will be instrumental in involving individual landowners, developing site-specific plans, and obtaining funding assistance.

Table 10-2: General grazing BMPs and management techniques (from NRCS 2001, and DNRC 1999).

BMP and Management Techniques	Pollutants Addressed
Design a grazing management plan and determine the intensity, frequency, duration, and season of grazing to promote desirable plant communities and productivity of key forage species. In this case, native riparian	Sediment, temperature, nutrients
Encourage the growth of woody species (willow, alder, etc.) along the streambank, which will limit animal access to the stream and provide root support to the bank.	Sediment, nutrients, temperature
Establish riparian buffer strips of sufficient width and plant composition to filter and take up nutrients and sediment from concentrated animal feeding operations.	Sediment, nutrients,
Create riparian buffer area protection grazing exclosures through fencing.	Sediment, temperature, nutrients
Maintain adequate vegetative cover to prevent accelerated soil erosion, protect streambanks, and filter sediments. Set target grazing use levels to maintain both herbaceous and woody plants.	Sediment
Ensure adequate residual vegetative cover and regrowth by rest or deferment periods. Periodically rest or defer riparian pastures during the critical growth period of plant species.	Sediment, nutrients
Distribute livestock to promote dispersion and decomposition of manure and to prevent the delivery of manure to water sources.	Nutrients
Alternate a location's season of use from year to year. Early spring use can cause trampling and compaction damage when soils and streambanks are wet. If possible, develop riparian pastures to be managed as a separate unit through fencing.	Nutrients, sediment
Provide off-site, high quality water sources.	Nutrients, sediment
Periodically rotate feed and mineral sites and generally keep them in uplands.	Nutrients, sediment
Place salt and minerals in uplands, away from water sources (ideally ¼ mile from water to encourage upland grazing).	Sediment, nutrients, temperature
Monitor livestock forage use and adjust strategy accordingly.	Sediment, nutrients, temperature
Create hardened stream crossings.	Sediment

10.4.1.1 Animal Feeding Operations

Animal Feeding Operations (AFOs) can pose a number of risks to water quality and public health due to the amount of animal manure and wastewater they generate. To minimize water quality and public health impacts from AFOs, and land applications of animal waste, the USDA and EPA released the Unified National Strategy for AFOs in 1999 (NRCS 2005). This strategy encourages owners of AFOs of any size or number of animals to voluntarily develop and implement site specific Comprehensive Nutrient Management Plans (CNMPs) by 2009. This plan 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 Concentrated Animal Feeding Operation (CAFO), and in addition, 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, which additionally increase property values and operation productivity. Properly installed vegetative filter strips in conjunction with other practices to reduce waste loads 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 (NRCS 2005). Other installations may include clean water diversions, roof gutters, berms, sediment traps, fencing, structures for temporary manure storage, shaping, and grading. Animal health and productivity also benefits when clean, alternative water sources are installed to prevent contamination of surface water. Studies have shown benefits in red meat and milk production of 10 to 20 percent by livestock and dairy animals when good quality drinking water is substituted for contaminated surface water.

Opportunities for financial and technical assistance in achieving voluntary AFO and CAFO compliance are available from conservation districts and NRCS field offices. Voluntary participation may aide in preventing a more rigid regulatory program from being implemented Montana Nonpoint Source Management Plan for Montana livestock operators in the future.

Further information may be obtained from the DEQ website at: http://www.deq.mt.gov/wqinfo/mpdes/cafo.asp. Montana's NPS pollution control strategies for addressing AFOs are summarized in the bullets below:

- Work with producers to prevent NPS pollution from AFOs.
- Promote use of State Revolving Fund for implementing AFO BMP's.
- Collaborate with 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 & 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 internal (Permitting Division), as well as external entities (DNRC, local watershed groups, conservation districts, MSU Extension, etc.).

10.4.1.2 Riparian Vegetation Restoration

Reduction of riparian vegetative cover is a principal cause of water quality and habitat degradation in the upper Big Hole area. Although implementation of grazing, irrigation and agricultural BMPs would promote recovery of riparian communities, the severity of the impairment, and critical status of Arctic grayling, suggests that natural recovery rates may be insufficient in many stream reaches to meet conservation goals in a timely manner for protection of this species of special concern. All areas that are actively restored with vegetation must have a reasonable approach to protecting the invested effort from further degradation from livestock or hay production.

Riparian planting will be necessary to achieve some stream targets within a desirable period. Riparian vegetation planting and transplanting measures are expected to be included in the CCAA landowner plans. Factors influencing the appropriate riparian restoration would include severity of degradation, site-potential for various species, and availability of local sources for transplant materials. In general, riparian plantings would promote establishment of functioning stands of native species (grasses and willows). The following recommended restoration measures would allow for stabilization of the soil, decreasing sediment delivery to the stream, and increasing absorption of nutrients from overland runoff.

- Harvest and transplant locally available sod mats with an existing dense root mass which provide immediate promotion of bank stability and filtering nutrients and sediments.
- Transplanting mature shrubs, particularly willows (*Salix* sp.), provides rapid restoration of in-stream habitat and water quality through overhead cover and stream shading as well as uptake of nutrients.
- Seeding with native graminoids (grasses and sedges) and forbs is a low cost activity where lower bank shear stresses would be unlikely to cause erosion.
- Willow sprigging would expedite vegetative recovery, involving harvest of dormant willow stakes from local sources.

10.4.1.3 Streambank/Floodplain Restoration BMPs

Bank erosion associated with willow removal and livestock grazing practices are a major source of sediment. Reductions in streamside willows appeared to have resulted in some overly wide and shallow channel segments. Over widened channels can lead to accumulations of fine sediment in pools, because of reduced sediment transport efficiencies and may produce a stream channel with fewer or lower quality pools containing increased sediments. Over widened channels increase sediment concentrations and water temperatures, thus reducing aquatic habitat quality.

These general restoration activities focus on enhancing suitable in-stream habitat for native fishes and fostering a quicker recovery time for stream channels, bank erosion and riparian vegetation shading. These restoration activities would assist in meeting sediment, temperature, and nutrient TMDL targets in stream reaches that have historically been heavily altered by grazing, channeling, mining, transportation, or haying activities. Actual restoration activities would be determined on a site-by-site basis and would depend on the relationships among shrub cover, width-to-depth ratios, eroding banks, and pool frequency.

The Big Hole River was a braided channel supporting dense stands of riparian shrubs. This system did not contain large woody debris from cottonwoods or large rocks providing grade control. Therefore, common stream restoration techniques such as root wads, rock veins, and log veins are inappropriate in the upper Big Hole. Moreover, the use of large wood may favor non-native brook trout. Instead, this restoration strategy proposes measures consistent with the historic nature of the Big Hole River and the habitat needs of the Arctic grayling. These stream restoration measures are:

- Braid reactivation of naturally braided Rosgen type Da channels where each channel is an E/C channel. This is a relatively inexpensive measure generally increasing habitat suitability and availability while decreasing stream temperature. This dissipates energy at higher flows and allows for more riparian shade, where appropriate.
- Mechanical bank stabilization using transplanted vegetation, sod mats, and willow cuttings to decrease sedimentation and enhance long term bank stability.
- Pool creation or enhancement includes excavation of a pool on the outside bend of a meander. Revegetation using sod mats, seeding, willow sprigging, or willow transplants would probably accompany these activities. This technique would be useful in increasing pool frequency and improving width-to-depth ratios as well as improving habitat for native fish and other aquatic life (see **Figure 10-1**).
- Channel narrowing and redefinition. Channel narrowing would be similar to pool creation, except it would occur on a greater scale. The basic steps would include excavation of pools combined with narrowing of the channel through construction of gravel point bars and revegetation/bank stabilization (see **Figure 10-1**). Complex woody debris may also be placed in pools with approval from MFWP.

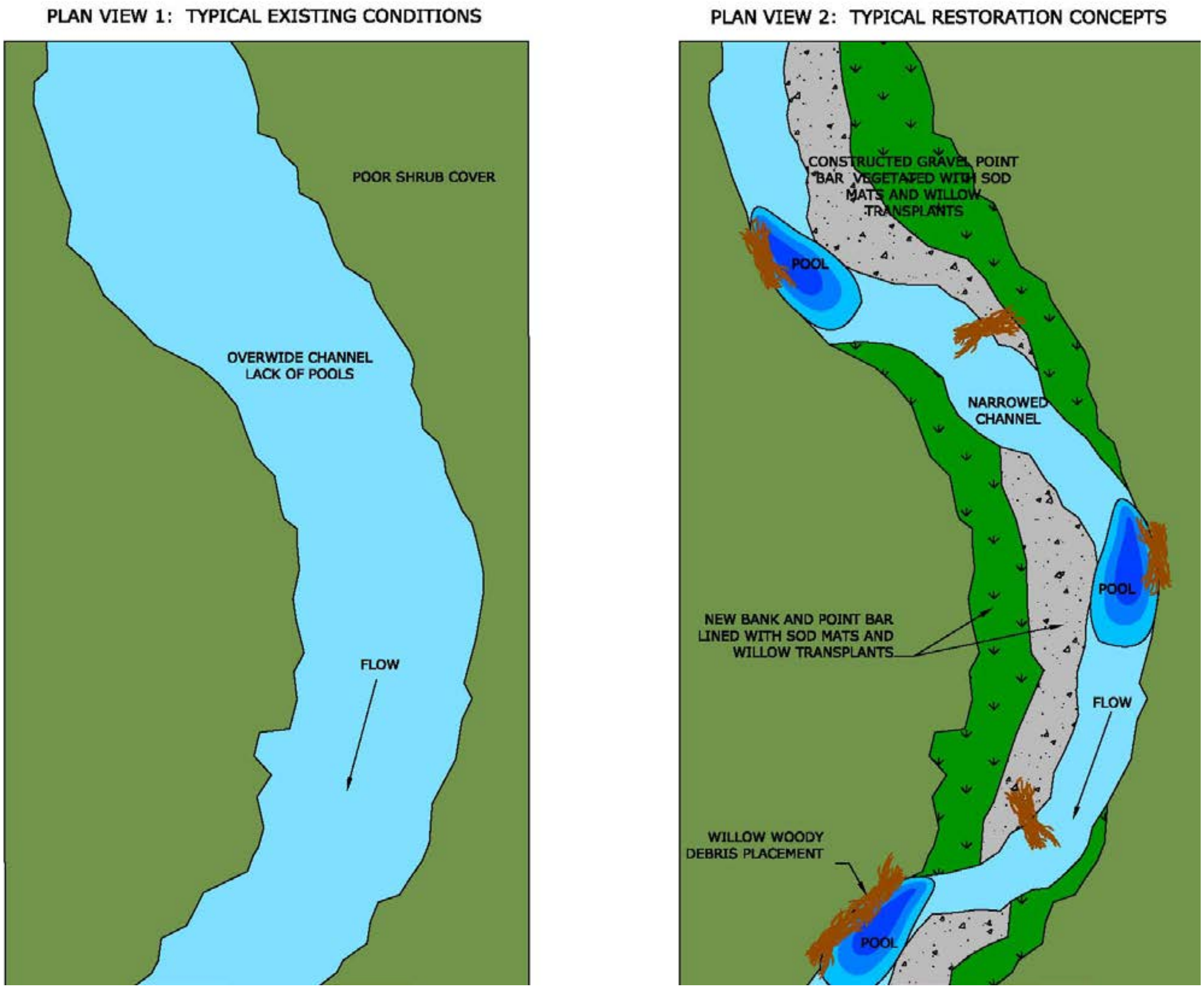


Figure 10-1: Schematic illustration of pool creation and channel redefinition in the Big Hole River.

10.4.2 Irrigation Management

Irrigation efficiency management practices in the Big Hole Watershed should involve investigating how to reduce the amount of stream water diverted during July and August while still growing crops on traditional cropland. It may be desirable to promote inefficient irrigation practices earlier in the year to promote groundwater return during July and August. Understanding irrigation water, groundwater, and surface water interactions is an important part of understanding how irrigation practices will affect stream flow during specific seasons.

Irrigation management is a critical component of attaining both Arctic grayling conservation and TMDL goals. The CCAA (MFWP and USFWS 2005) provides a plan to meet stream flow targets, and these stream flows will help meet temperature goals with increased flows. The CCAA landowner agreements detail a site-specific approach to irrigation management, the responsible parties, and an implementation schedule. This implementation strategy includes a brief description of these measures and some additional activities not covered in the CCAA.

The CCAA includes three categories of conservation actions to promote maintenance of adequate flows in the Big Hole River. These focus on irrigation diversions and delivery and are as follows:

- Improving the participating landowner's control of diversion, delivery, and measurement of water;
- Reducing the amount of diverted water; and
- Increasing the effectiveness with which diverted water is delivered to irrigated lands.

Overall, these activities are designed to increase water use efficiency to keep flows in the river while meeting the producer's forage production goals. Formal agreements for implementation of these actions are part of the CCAA for enrolled landowners. The CCAA partner agencies, NRCS and DNRC, will be responsible for developing water management plans for participating landowners and ensuring implementation of conservation measures. These landowner agreements include provisions for an implementation schedule requiring that implementation activities begin no later than the date upon which the site-specific landowner plan is finalized

10.4.2.1 Dewatering

Irrigation diversion has reduced the magnitude and duration of flows in the Big Hole River and tributary streams, especially during irrigation season from April through September. Flow reduction may increase water temperature, allows sediment to accumulate in stream channels, 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 (Andrews and Nankervis 1995, Schmidt and Potyondy 2004). These alterations have the potential to result in sediment movement problems, temperature increases, and also result in reduction of aquatic organism habitat quality depending on location within the watershed.

Aerial photo analyses and field reconnaissance of the Big Hole River and tributary streams has identified some reaches where stream flows may be insufficient to maintain channel integrity. Streams and reaches with compromised channel definition below irrigation diversions have been inventoried for sections of the mainstem of the Big Hole River, Steel Creek, Warm Springs Creek, Governor Creek, Rock Creek, and Swamp Creek. Field observations identified stream channel alterations on these streams as well as Johnson Creek, Mussigbrod Creek, and North Fork Big Hole River. These alterations included excessive fine sediment on the streambed, and loss of streambed complexity (especially pool habitat). The effects of recent droughts have probably exacerbated these effects on channel integrity.

10.4.2.2 Irrigation Flow Restoration Recommendations

Achieve minimum flow targets/channel maintenance flows.
The CCAA establishes minimum flow targets for the Big Hole River, designed to provide adequate flows within critical habitat. It is unknown if these flows can be maintained by installing and using all reasonable irrigation efficiency management practices. All reasonable

irrigation efficiency management practices should be pursued on a voluntary basis. Maintaining these minimum flows in the Big Hole River will require that minimum flows also be maintained in at least some of the tributary streams within the CCAA area. Although these flows will benefit Arctic grayling and improve water quality, they will not affect streams outside of the CCAA area, and will not result in a flow regime that maintains sediment transport.

Channel maintenance flows help maintain the hydraulic conditions necessary for a channel to remain fully functioning for sediment transport and flow conveyance. Channel maintenance flows also help maintain instream habitat features for Arctic grayling, particularly deep pools for holding cover and development of gravel bars for spawning habitat. Channel maintenance flows should be considered as a viable restoration approach in all areas where channel definition and instream sediment sorting issues are identified.

Improving Irrigation Efficiency
Current irrigation practices are based on flood irrigation methods. Many head gates and ditches leak, which can decrease the amount of water in in-channel flows.

Irrigation Efficiency Restoration Recommendations
The following recommended activities would result in notable water savings.

- Install upgraded head gates for more exact control of water diversions, and to minimize leakage when not in operation.
- Develop more efficient means to supply water to livestock.
- Determine necessary amounts of water to divert that would reduce over watering and improve forage quality and production.
- Redesign irrigation systems.
- Upgrade ditches (including possible lining) to increase ditch conveyance efficiency.
- Redisign the composition and distribution of irrigated crops.

The CCAA (MFWP and USFWS 2005) program includes a provision for the NRCS to conduct a comprehensive investigation of existing attributes of water rights on the enrolled lands by considering factors such as water holding capacity of the soils, the water requirement of the crops, variability in environmental conditions, and cooperative use with adjacent landowners. This investigation will enable the NRCS to determine the suitable irrigation diversion amount needed for production of crops. This investigation will occur within 30 months of participant enrollment. Following determination of the CCAA diversion amount, enrolled landowners will have flexibility to upgrade their irrigation systems using one or several of the listed recommended options above.

The CCAA applies only to enrolled landowners in the upper Big Hole River planning area. However, the Big Hole Watershed Committee (BHWC), in conjunction with the NRCS and DNRC, will work with interested landowners throughout the upper basin to upgrade their systems and alter cropping and irrigation practices. These potential water savings will add to in channel flows, reduce summer water temperatures, and benefit Arctic grayling, the native fish assemblage, and associated aquatic life. Priority stream sites include stream segments lacking channel definition below diversions, on nutrient and temperature listed streams, where increased flows may assist in nutrient and thermal load dilution and increase the streams' assimilative capacity.

Ground water and surface water are connected. Irrigation plays a role in the amount of ground water in many areas of the Big Hole River Watershed. The most limiting timeframe in the Big Hole River for both irrigators and aquatic life occurs during the heat of the summer (July-early September). Irrigation efficiencies are only called for during hot weather periods for the temperature TMDLs. The timeframe it takes ground water to return to streams is not easily understood without specific study. The temperature TMDL uses general knowledge about irrigation and ground water influences within the project area. This is because of the scale of the project and difficulty in determining spatially and temporally specific groundwater return timeframes from irrigated areas. Therefore, further study should occur to determine time it takes ground water to travel to surface water within specific areas before large scale irrigation efficiency efforts are implemented. Further study should include any consideration of pivots or sprinklers, which may have a large affect upon ground water recharge rates and time of water use associated with water rights. Pivots are not always appropriate for preserving cool stream temperatures, yet may be appropriate in some areas if groundwater return from the irrigated area to streams is naturally delayed until cool weather timeframes when irrigation and evapotranspiration is not occurring.

Early season irrigation should consider both 1) stream flows which are necessary for channel formation and also 2) the ability for irrigation during this timeframe to recharge local aquifers. Spring time aquifer recharge has the potential to increase cool groundwater return flow during the heat of the summer. Irrigation efficiencies during the spring timeframe should not be implemented, unless bank full flood events are needed to scour stream channels and sort sediment within the channel. These two early season irrigation considerations should be balanced in concurrence with each other. Fertilizer application timeframes should also be considered for reducing nutrient runoff if excess water application occurs during high water.

10.4.3 Nutrient Management Planning

Nutrient management is managing the amount, source, placement, form, and timing of plant nutrients and soil amendments. Nutrient management components of the conservation plan should include the following information (NRCS MT 590-1):

- 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
- Nutrient budget, including credits of nutrients available
- Nutrient rates, form, timing, and application method to meet crop demands and soil quality concerns
- Location of designated sensitive areas
- Guidelines for operation and maintenance.

Nutrient management is most effective when used with other agronomic practices, such as cover or green manure crops, residue management, conservation buffers, water management, pest management, and crop rotation. More information about nutrient management techniques can be found at your local NRCS office or in the NRCS publication MT 590-1.

10.4.4 Unpaved Roads BMPs

The road sediment reduction represents the estimated sediment load that would remain once all contributing road treads, cut slopes, and fill slopes were reduced to the maximum of 500 feet in mountainous settings and 100 feet in valley settings. These measurements were selected as an example to illustrate the potential for sediment reduction through BMP application and are not a formal goal at every crossing. For example many road crossings in mountainous settings can easily have a smaller contributing length than 500 ft, while others may not be able to meet a 500ft milestone. The best practical BMPs should be assessed and constructed starting with the most problematic road segments. Achieving the reductions in sediment loading called for in the TMDLs from the road system may occur through a variety of methods at the discretion of local land managers and restoration specialists. Undersized culverts should be replaced to pass at least a 50-100 year flood event if they fail.

Assessments should occur for roads within watersheds that experience timber harvest or other major land management operations. The information gathered during these assessments will allow for timely feedback to land managers about the impact their activities could have on water quality and achievement of TMDL targets and allocations. This feedback mechanism is intended to keep sediment load calculations current and avoid new road impacts that go undetected for an extended period of time.

10.4.5 Road Sanding

Application of sand to highways during winter months has the potential to increase loading of fine sediment (< 2 mm in diameter) to surface waters in the upper Big Hole River planning area. Source assessments for this category of fine sediment delivery included spatial evaluations of roads adjacent to streams, and a study commissioned by the Montana Department of Transportation (MDT) to evaluate contributions to select streams in the basin (Hydrometrics 2005). Essentially, this study provides many components of the TMDL with respect to this potential source of fine sediment. This includes a source assessment, evaluation of the relative contribution, and a basis to allocate an allowable load from this source.

Field reconnaissance investigations indicated stream crossings and stream adjacent reaches of highway were the features associated with potential delivery of road traction sand to surface waters (Hydrometrics 2005). Sand entered highway adjacent reaches after being thrown or washed down embankments; however, presence of a flat, vegetated drainage bottom between the embankment and stream impeded most of the delivery to streams. Observers identified ten reaches presenting a sediment delivery risk (**Table 10-3**) and rated these according to their potential to deliver sediment based on a questionnaire that evaluated distance from road to stream, percent vegetative cover, slope of the embankment, observed presence of sand, and evidence of conveyance.

Table10-3: Field reconnaissance results for Trail Creek stream segments proximal to Highway 43 (Hydrometrics 2005).

Stream Reach ID	Relative Road Sand Loading Potential (field inspection score)*	Stream Length Adjacent to Road Embankment	Average Distance Road Shoulder to Stream
TC-1	Low (10.0)	250	20
TC-2	Low (9.5)	300	30
TC-3	High (14.0)	300	15
TC-4	Low (9.0)	150	20
TC-5	High (12.5)	100	25
TC-6	High (12.5)	100	20
TC-7	High (12.5)	40	30
TC-8	Medium (12.0)	100	30
TC-9	Medium (12.0)	100	20
TC-10	Medium (12.0)	700	25

* Relative road sanding loading potential based on GIS analysis and field reconnaissance. Ratings are relative.

Stream crossings also presented risks for sediment loading along Highway 43 with 11 crossings identified as having moderate to high loading potential (**Table 10-4**). Factors contributing to delivery potential included distance of road to the stream, vegetative cover between road and stream, presence of road sand, and evidence of delivery of road sand to the stream. Road sand was attributable for a sharp contrast in substrate composition at several crossings. Sand comprised a majority of observed size fractions at these locations.

Table 10-4: Stream crossings with identified potential to deliver traction sand to surface waters in the Trail Creek drainage (Hydrometrics 2005).

Site	Stream Name	Crossing Type	Relative Loading Potential
TCX-1	Trail Creek	Bridge	High
TCX-2	Sheep Creek	Culvert	Moderate
TCX-3	Trail Creek	Bridge	High
TCX-4	May Creek	Culvert	Moderate
TCX-5	Trail Creek	Bridge	High
TCX-6	Canyon Creek	Culvert	Moderate
TCX-7	Cascade Creek	Culvert	Moderate
TCX-8	Sage Creek	Culvert	Moderate
TCX-9	Runaway Creek	Culvert	Moderate
TCX-10	Placer Creek	Culvert	Moderate
TCX-11	Trail Creek	Bridge	High

* Relative loading potential based on GIS analysis and field reconnaissance.

The Hydrometrics study (2005) also assessed loads from the different source areas. Roadside embankments delivered 0.54 tons of sand to streams, and delivery at road crossings totaled 0.90

tons of sand, for 1.44 tons/year in the 2004-2005 winter season. Although road traction sanding and fill erosion are a small proportion of the overall sediment loads, allocations are provided. Allocations for sediment contributed from road traction sanding are based on BMPs presented in **Table 10-5**.

Table 10-5: Road traction sanding BMPs on Highway 43 (MDT 2005).

Number	Description
1	Increasing salt concentration in the sand stockpile, which causes snowpack on the roadway to break up faster so fewer sand applications are necessary
2	Pre-wetting of sand/ salt with liquid magnesium chloride, which causes more of the road sand to stay on the roadway longer, instead of being blown off by traffic
3	Pre-application of liquid magnesium chloride, which, under proper conditions, keeps snowpack from forming a tight bond to the road surface
4	Recovering sand from the roadway, shoulders, ditches, and around guardrails, so the sand does not wash farther down slope
5	not applicable along this section of road.
6	Installation and monitoring of silt fences, especially in areas below the fill slopes where sand is being transported from the toe of the fill slope toward a stream
7	Redirecting the snow blower onto fill slopes, which allows the sand that lands on the fill slope with the snow to be captured and stabilized by fill slope vegetation
8	Accurate record keeping to track sand application and recovery rates and inform road maintenance management through the adaptive management approach

10.5 Recent Restoration Activities

A high level of restoration activities have occurred since the initiation of the TMDLs in this planning area or are currently underway due to Fluvial Arctic Grayling CCAA (candidate conservation agreement with assurances) restoration efforts. Generally, most of these restoration efforts promote reductions in sediment, heat and nutrient loads or help to alleviate current loads through increased buffering capacities of the streams in the Upper Big Hole Valley. **Table 10-6** identifies the differing types of restoration projects which include of irrigation and stock water efficiencies, riparian vegetation restoration, stream bank restoration, moving corrals off of streams, and livestock fencing for improving riparian grazing management.

Table 10-6. Fluvial Arctic Grayling CCAA Restoration Projects

CCAA Segment	TMDL Reach (Appendix K-4)	Project Title	Year Complete d	Restoration (miles)	Fence (miles)	Headgates	Diversions	Fish ladder	Measuring Devices	Fish screens	Stockwate r well
above Miner Cr. bridge	BH13, BH14	Jackson Reach Restoration	2007	0.75	1	0	0	0	0	0	0
above Miner Cr. bridge	BH14, BH15	Schindler Restoration	2008	0	1	0	0	0	0	0	0
above Miner Cr. bridge	BH14	Schindler Feedlot	2006	0	0	0	0	0	0	0	1
above Miner Cr. bridge		Dooling Livestock Well	2007	0	0	0	0	0	0	0	1
above Miner Cr. bridge	GC09, GC10	Governor Creek Culvert Replacement	On-Going	0.25	0	0	0	0	0	0	0
above Miner Cr. bridge		Mitchell Fish Ladder	2007	0	0	0	0	1	0	0	0
above Miner Cr. bridge		M Jackson Diversions/Fish Ladders	2006	0	0	2	2	2	0	0	0
Segment Subtotal				***1***	***2***	***2***	***2***	***3***	***0***	***0***	***2***
Miner Cr. to Little Lake Cr. bridge	WS12, WS13, WS14	Warm Springs Fence/Finch	2008	0	3	0	0	0	2	0	0
Miner Cr. to Little Lake Cr. bridge		Warm Springs Stock Water/Lapham	2008	0	0	0	0	0	0	0	1
Miner Cr. to Little Lake Cr. bridge		Johnson Headgates	2005	0	0	2	0	0	2	0	0
Miner Cr. to Little Lake Cr. bridge	WS09	Warm Springs Fence/ Lapham	2009	0	0.7	0	0	0	0	0	0
Miner Cr. to Little Lake Cr. bridge	BH16	Big Hole - Lapham Riparian Fence	2008	0	0.6	0	0	0	0	0	0
Miner Cr. to Little Lake Cr. bridge		John Jackson Wetland Restoration	2007	0	0	0	0	0	0	0	0
Miner Cr. to Little Lake Cr. bridge		Johnson Riparian Fence	2009	0							
Miner Cr. to Little Lake Cr. bridge		Husted/Hirschy Diversions	2006	0	0	3	1	0	2	0	0
Miner Cr. to Little Lake Cr. bridge		John Jackson Riparian Fence	2008								
Segment Subtotal				***0***	***4.3***	***5***	***1***	***0***	***6***	***0***	***1***
Little Lake Cr. to Wisdom bridge	RO05, RO06	Rock Creek Restoration	2007	2.5	5	1	1	1	0	0	0
Little Lake Cr. to Mudd Cr. bridge	BH25, BH26	Wisdom Reach Restoration	2007	1.75	3.5	0	0	0	0	0	0
Little Lake Cr. to Wisdom bridge	BH19	Big Hole/Little Lake Creek	2008	2	4.5	0	0	0	0	0	0

Table 10-6. Fluvial Arctic Grayling CCAA Restoration Projects

CCAA Segment	TMDL Reach (Appendix K-4)	Project Title	Year Completed	Restoration (miles)	Fence (miles)	Headgates	Diversions	Fish ladder	Measuring Devices	Fish screens	Stockwater well
		Restoration									
Little Lake Cr. to Wisdom bridge	BH24	McDowell Reach Restoration	2008	6	12	0	0	0	0	0	0
Little Lake Cr. to Wisdom bridge	BH24	Spokane Diversion - Fish Ladder	2003	0	0	0	0	1	0	0	0
Little Lake Cr. to Wisdom bridge		Huntley Headgates	2008	0	0	4	3	0	2	0	0
Little Lake Cr. to Wisdom bridge		Maverick Headgate	2006	0	0	1	0	0	0	0	0
Little Lake Cr. to Wisdom bridge	BH24	Hirschy Diversion	2006	0	0	1	2	0	0	0	0
Little Lake Cr. to Wisdom bridge		Peterson Feedlot	2007	0.2	0.5	0	0	0	0	0	0
Little Lake Cr. to Wisdom bridge		Big Hole Grazing Association Well	2008	0	0	0	0	0	0	0	1
Little Lake Cr. to Wisdom bridge		Nelson Fish Ladders (Rock,Big Lake Cr)	2008	0	0	0	0	2	0	0	0
Little Lake Cr. to Wisdom bridge		Hirschy Bank Restoration	2008	0.1	0	0	0	0	0	0	0
Little Lake Cr. to Wisdom bridge		Huntley Pasture/Riparian Fence	2008	0	3	0	0	0	0	0	0
Little Lake Cr. to Wisdom bridge		HHirschy Little Lake Stock Well	2008	0	0	0	0	0	0	0	1
Little Lake Cr. to Wisdom bridge		HHirschy Ruby Wells	2008	0	0	0	0	0	0	0	2
Little Lake Cr. to Wisdom bridge		HHirschy Headgate and Diversion	2008	0	0	1	1	0	1	0	0
Little Lake Cr. to Wisdom bridge		Nelson Rock Creek Fence	2008	0	0.75	0	0	0	0	0	0
Little Lake Cr. to Wisdom bridge		Nelson Stock Wells	2009	0	0	0	0	0	0	0	2
Little Lake Cr. to Wisdom bridge		Huntley Fish Ladder	2006	0	0	0	0	1	0	0	0
Little Lake Cr. to Wisdom bridge		Wisdom River Fence (Upper Rock Creek)	2008	0	1	0	0	0	0	0	0
Little Lake Cr. to Wisdom bridge		Rock Creek Fish Ladder (Erb)	2007	0	0	0	0	1	0	0	0
Segment Subtotal				***12.55***	***30.25***	***8***	***7***	***6***	***3***	***0***	***6***
Wisdom to Mudd Cr. bridge	NF09, NF10	North Fork Fish Screens	2008	0	0	0	0	0	0	2	0
Wisdom to Mudd Cr. bridge	SW08, SW09, SW10	Swamp Creek Riparian Fence	2008	0	12	0	0	0	0	0	0
Wisdom to Mudd Cr. bridge	BH26, BH27	Big Hole - Harrington Riparian Fence	2008	0	5	0	0	0	0	0	0

Table 10-6. Fluvial Arctic Grayling CCAA Restoration Projects

CCAA Segment	TMDL Reach (Appendix K-4)	Project Title	Year Completed	Restoration (miles)	Fence (miles)	Headgates	Diversions	Fish ladder	Measuring Devices	Fish screens	Stockwater well
Wisdom to Mudd Cr. bridge		Steel Creek Diversions	2008	0	0	1	1	0	0	0	0
Wisdom to Mudd Cr. bridge	SC06, SC07	Steel Creek Riparian Fence	2003	0	3	0	0	0			
Wisdom to Mudd Cr. bridge		York Gulch Riparian Fence	2008	0	3.5	0	0	0	0	0	0
Wisdom to Mudd Cr. bridge		Quarter Circle 3T Stock Well	2008	0	0	0	0	0	0	0	1
Wisdom to Mudd Cr. bridge		York Gulch Diversions	2008	0	0	5	5	5	5	0	0
Segment Subtotal				***0***	***23.5***	***6***	***6***	***5***	***5***	***2***	***1***
Mudd Cr. to Dickie bridge		Big Hole - Christiansen Riparian Fence	2008	0	2.85	0	0	0	0	0	0
Mudd Cr. to Dickie bridge		Ralston Big Hole Riparian Fence	2007	0	3.2	0	0	0	0	0	0
Mudd Cr. to Dickie bridge		Fishtrap Riparian Fence	2007	0	1	0	0	0	0	0	0
Mudd Cr. to Dickie bridge		Lamarche Creek Stock Water	2008	0	0	0	0	0	0	0	2
Mudd Cr. to Dickie bridge		Fishtrap Habitat Enhancement	2005	0.5	0	0	0	0	0	0	0
Mudd Cr. to Dickie bridge		Lamarche Creek Habitat Enhancement	2006	1	0	0	0	0	0	0	0
Mudd Cr. to Dickie bridge		Lamarche Creek Riparian Fence	2004	0	2.5	0	0	0	0	0	0
Mudd Cr. to Dickie bridge		Deep Creek Riparian Fence	2006	0	1	0	0	0	0	0	0
Mudd Cr. to Dickie bridge		Fishtrap Creek - Ernie Bacon Stock Wells	2008	0	0	0	0	0	0	0	2
Mudd Cr. to Dickie bridge		Reinhardt Stock Water Wells	2007	0	0	0	0	0	0	0	3
Mudd Cr. to Dickie bridge		Ralston Big Hole Stock Well	2008	0	0	0	0	0	0	0	1
Mudd Cr. to Dickie bridge		Ralston Deep Creek Stock Well	2008	0	0	0	0	0	0	0	1
Mudd Cr. to Dickie bridge		Fishtrap Luckey Stock Water	2008	0	0	0	0	1	0	0	0
Segment Subtotal				***1.5***	***10.55***	***0***	***0***	***1***	***0***	***0***	***9***
Totals				**15.05**	**70.6**	**21**	**16**	**15**	**14**	**2**	**19**

10.6 Watershed Restoration Summary

The most important restoration efforts for implementation in the upper and North Fork Big Hole Watersheds will be to restore and protect riparian vegetation. Restoring riparian areas will provide the most sediment, nutrient, and thermal load reductions. A tiered approach for restoring stream channels and adjacent riparian vegetation should consider the existing conditions of the stream channel and adjacent vegetation. In non-conifer dominated areas, the restoration goals should focus on restoring natural shrub cover on streambanks to reference levels which are provided by the sediment, nutrient and temperature TMDL riparian vegetation targets. In areas with little to no shrub vegetation exists in non-conifer dominated riparian zones, active natural shrub reintroduction should occur, especially where CCAA and TMDL objectives overlap. In areas where stream channels are unnaturally stable or streambanks are eroding excessively, active restoration approaches such as channel design, bank sloping, seeding and shrub planting may be needed.

All riparian areas should be protected against excessive hoof sheer, over grazing, and especially over browsing. In many cases where riparian areas are heavily impacted, protection may need a number of years rest with careful deferment or rotation schedules thereafter. In areas meeting riparian, stream channel, and other targets, these protections should continue with active grazing and hay management. Active riparian grazing management is important for long term health of riparian zones. When actively managing these zones after restoration when shrub health has increased, browse should be kept to a minimum. These areas should be utilized during specific seasons that promote grazing and not browsing. Grazing use of riparian areas should also occur quickly and only when sufficient forage is available. Grazing systems should be dynamic and based upon measures of browse, hoof sheer and stubble height only after sufficient shrubs have been allowed to recover. Weed management should also be a dynamic component of managing riparian areas as they recover.

Other restoration activities called for by the TMDLs include nutrient management on irrigated areas, unpaved road BMPs, and road sanding BMPs on Lost Trail Pass.

SECTION 11.0
MONITORING STRATEGY AND ADAPTIVE MANAGEMENT

11.1 Introduction

This section provides a monitoring strategy to strengthen the TMDLs presented in this report, assess water quality issues on water bodies that are not currently listed but may be impaired, and determine the effectiveness of restoration activities recommended in Section 10.0 once they are implemented. Funding for future monitoring is uncertain and variable due to economic and political change. Prioritization of monitoring activities depends on stakeholder priorities for restoration activities and funding opportunities.

11.2 Future Monitoring Guidance

A number of future monitoring objectives are identified in the Upper and North Fork Big Hole Watershed. A portion of the monitoring identified in this section is proposed to observe how sediment, temperature and nutrient conditions change over time as restoration activities occur. Another goal of future monitoring will be to strengthen current TMDL source assessments in limited areas before well-informed restoration can occur. A third objective of monitoring identified in this section identifies streams and pollutants that should be investigated further because there are indications that TMDLs may be needed.

11.2.1 Strengthening Source Assessment Prior to Restoration Work

11.2.1.1 Hydrology

A water balance and irrigation efficiency study should be conducted for the upper Big Hole valley. Additionally, the study should determine if the irrigation infrastructure or management can be modified to reduce/retain more instream flow during environmentally sensitive timeframes. Once feasible irrigation improvements are identified and planned, additional monitoring should be conducted to quantify irrigation effects to ground water conditions and ultimately surface water as improvements are implemented. As irrigation efficiency projects are implemented, effectiveness monitoring should occur to see how much water is saved by each project. An economic analysis of each irrigation efficiency project should also occur to determine the cost of the saved water. See the recently completed report for the Upper Jefferson River for an example approach to determining the most cost effective saving water alternatives. This effort would need local initiation. Funding would likely come from both local match and also federal and state sources.

11.2.1.2 Nutrients

Steel and Francis Creek nutrient TMDLs were completed during this TMDL development effort. Controllable human caused sources in these watersheds are agricultural based and restoration approaches involve riparian and upland grazing management along with fertilizer management. These restoration approaches are very reasonably implemented and clearly identified by the

TMDL source assessment and allocation approach. No further water quality nutrient monitoring is necessary before restoration activities begin. Prioritizing areas for riparian restoration could be based upon further riparian vegetation monitoring efforts, but local knowledge and professional judgment are acceptable approaches to prioritizing riparian restoration projects in both watersheds.

11.2.1.3 Sediment

If there is stakeholder interest to do so, future TMDL reviews could refine the allocation approach to include allocations specific to road ownerships such as BLM, county, private and USFS areas. Sediment allocations to roads and unpaved road restoration activities would likely benefit from this effort.

A sediment TMDL was written for Miner Creek even though very little restoration work can occur in this watershed. A more robust spatial sampling of stream bottom content and eroding bank monitoring in Miner Creek may be warranted before restoration work is completed. The results could indicate if future restoration work is necessary.

Additional monitoring is recommended to gain a better understanding of streambank retreat rates. Streambank retreat rates are part of the equation for calculating sediment loading from near-stream sediment sources for sediment TMDLs and allocation. The current sediment TMDLs are calculated using literature values for streambank retreat rates. Measuring streambank retreat rates on water bodies within the Upper and North Fork Big Hole TPA would be useful to verify or revise the bank retreat rates used in this effort and would also be useful for completing or revising sediment TMDLs in other watersheds throughout southwest Montana and other areas with similar settings. Bank retreat rates can be determined by installing a series of bank pins at different positions on the streambank at several transects in sites placed in a range of landscape settings 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.

Conditions relative to sediment production at unpaved road crossings should be monitored prior to and post restoration efforts. Pre and post restoration information should be applied to the same unpaved road model used for the TMDL sediment assessments. This approach would estimate sediment reduction from unpaved road erosion reduction projects.

11.2.1.4 Temperature

Irrigation returns can contribute heat to the water bodies to which they drain. Irrigation withdrawals can cause increases in stream temperature and reduce the efficiency of sediment routing. The irrigation network in the Upper Big Hole Valley is extensive and could not be fully assessed during this TMDL assessment. Irrigation also has a large influence on ground water in the upper Big Hole Valley, which in turn, influences surface water conditions. A more thorough assessment of irrigation water use above Wisdom would be useful for irrigation water management restoration activities. See the hydrology monitoring Section 11.2.1.1 for more guidance about hydrological assessment.

An aerial assessment of temperature trends of the upper Big Hole River using Forward-Looking Infrared (FLIR) technology would be useful for identifying influences of irrigation and groundwater on the temperature of the upper Big Hole River. Future efforts should identify all significant irrigation withdrawals and returns. A subset of these should be monitored for pollutant impacts to streams.

11.2.2 Impairment Status Monitoring

The Montana Department of Environmental Quality (DEQ) is the lead agency for developing and conducting impairment status monitoring. Other agencies or entities may work closely with the DEQ to provide compatible data if interest arises. Impairment determinations are conducted by the State of Montana but can use data from other collection sources. The following section provides general guidance for future impairment status monitoring.

11.2.2.1 Sediment

A sediment TMDL was not completed in Warms Springs Creek even though significant controllable human caused sources were present because sediment conditions in the stream could not be clearly linked to aquatic life impacts. Further stream bottom content and pool measurements should occur to verify this is the case. This monitoring would likely occur by the DEQ or via funding from the DEQ.

The DEQ is currently considering overall biological health and also sediment related metrics for periphyton assessments. These new metrics may provide additional relevant information relating to beneficial uses should be considered during future TMDL reviews.

11.2.2.2 Metals

Further copper monitoring and follow up 303d assessments should occur to determine if a TMDL or site specific standards are needed for Governor Creek. Further lead and copper monitoring and a follow up 303d assessment should occur to determine if a TMDL or site specific standards are needed for Joseph Creek. Lead should continue to be monitored in Mussigbrod Creek to determine if site specific standards are needed. Further cadmium and copper monitoring and a follow up 303d assessment should occur to determine if a TMDL or site specific standards are needed for Steel Creek.

11.2.2.3 Nutrients

A number of nutrient TMDLs were not pursued at this time. Some were not pursued due to their recent inclusion in Montana's 303(d) List. Others were not pursued because of the lacking knowledge about their extensive irrigation network which heavily influence stream flow and nutrient load. Future stream flow and nutrient monitoring should occur in Rock, McVey, Swamp, Fox, Pine and Warm Spring Creek watersheds prior to TMDL development to increase knowledge about nutrient conditions in each of these watersheds. Irrigation water management should also be investigated further in these watersheds during future TMDL development.

Future nutrient monitoring at or below Wisdom on the upper Big Hole River is warranted. Large algae mats are observed during summer low flow timeframes during a number of recent years. Little to no nutrient data are available to assess nutrient conditions in this reach of the Big Hole River. Part of the algae growth may be caused by increased sunlight due to over wide stream and warmed conditions from low stream flow in this area.

11.2.2.4 Temperature

A temperature TMDL for Pintlar Creek was not pursued at this time. Monitoring information produced from this effort did not provide enough information to determine if a TMDL was needed. Further monitoring of irrigation system water use is recommended. A more robust aerial photo assessment and associated riparian vegetation shade monitoring may be necessary.

11.2.3 Effectiveness Monitoring for Restoration Activities

The following recommendations are categorized by the type of restoration practice to which they apply.

11.2.3.1 Road BMPs

Monitoring road sediment delivery is necessary to determine if BMPs are effective, to determine which are most effective, and to determine which practices or sites require modification to achieve water quality goals. Effectiveness monitoring should be initiated prior to implementing BMPs at treatment sites.

Monitoring actual sediment routing is difficult or prohibitively expensive. It is likely that budget constraints will influence the number of monitored sites. A detailed monitoring study design should be developed once specific restoration projects are identified. Monitoring at specific locations should continue for a period of 2-3 years after BMPs are initiated to overcome environmental variances.

Specific types of monitoring for separate issues and improvements are listed in **Table 11-1**.

Table 11-1: Monitoring Recommendations for Road BMPs.

Road Issue from Section 10.0 (Restoration)	Restoration Recommendations	Monitoring Recommendation	Recommended Methodology
Ditch Relief Combined with Stream Crossings	• Re-engineer & rebuild roads to completely disconnect inboard ditches from stream crossings. Techniques may include: o Ditch relief culverts o Rolling dips o Water Bars o Outsloped roads o Catch basins o Raised road grade near stream crossing	• Place silt trap directly upslope of tributary crossing to determine mass of sediment routed to that point • Rapid inventory to document improvements and condition	• Sediment yield monitoring based on existing literature/USFS methods • Revised Washington Forest Practices Board methodology
Ditch Relief Culverts	• Consider eliminating the inboard ditch and outsloping the road or provide rolling dips • When maintaining/ cleaning ditch, do not disturb toe of cutslope • Install culverts with proper slope and angle following Montana road BMPs • Armor culvert outlets • Construct stable catch basins • Vegetate cutslopes above ditch • Increase vegetation or install slash filters, provide infiltration galleries where culvert outlets are near a stream	• Rapid inventory to document improvements and condition • Silt traps below any ditch relief culvert outlets close to stream	• Revised Washington Forest Practices Board methodology • Sediment yield monitoring based on existing literature/USFS methods
Stream Crossings	• Place culverts at streambed grade and at base of road fill • Armor and/or vegetate inlets and outlets • Use proper length and diameter of culvert to allow for flood flows and to extend beyond road fill	• Repeat road crossing inventory after implementation • Fish passage and culvert condition inventory	• Revised Washington Forest Practices Board methodology • Montana State (DNRC) culvert inventory methods

Table 11-1: Monitoring Recommendations for Road BMPs.

Road Issue from Section 10.0 (Restoration)	Restoration Recommendations	Monitoring Recommendation	Recommended Methodology
Road Maintenance	• Avoid casting graded materials down the fill slope & grade soil to center of road, compact to re-crown • Avoid removing toe of cut slope • In some cases (primarily Ramshorn Creek Road) graded soil may have to be removed or road may have to be moved	• Repeat road inventory after implementation • Monitor streambed fine sediment (grid or McNeil core) and sediment routing to stream (silt traps) below specific problem areas	• Revised Washington Forest Practices Board methodology • Standard sediment monitoring methods in literature
Oversteepened Slopes/General Water Management	• Where possible outslope road and eliminate inboard ditch • Place rolling dips and other water diverting techniques to improve drainage following Montana road BMPs • Avoid other disturbance to road, such as poor maintenance practices and grazing	• Rapid inventory to document improvements and condition	• Revised Washington Forest Practices Board methodology

11.2.3.2 Agricultural BMPs

Management improvements related to grazing, irrigation, and crop production have been implemented in many areas throughout the Upper and North Fork Big Hole River TPA. These projects have been implemented through NRCS, State, other federal, or private funds, and often include monitoring specific to those projects. Additional monitoring is recommended below for future improvements and projects.

Grazing BMPs function to reduce grazing pressure along streambanks and riparian areas. Recovery resulting from implementing BMPs may be reflected in improved water quality, channel narrowing, cleaner substrates, and recovery of vegetation along streambanks and riparian areas. Effectiveness monitoring for grazing BMPs should be conducted over several years, making sure to start monitoring prior to BMP implementation. If possible, monitoring reaches should be established in pastures keeping the same management as well as in those that have changed. Where grazing management includes moving livestock according to riparian use level guidelines, it is important to monitor changes within the growing season as well as over several years. Monitoring recommendations to determine seasonal and longer-term changes resulting from implementing grazing BMPs are outlined below in **Table 11-2**.

Table 11-2: Effectiveness Monitoring Recommendations for Grazing BMPs by Restoration Concern.

Recovery Concern	Monitoring Recommendations	Methodology or Source
Seasonal impacts on riparian area and streambanks	Seasonal monitoring during grazing season using riparian grazing use indicators • Streambank alteration • Riparian browse • Riparian stubble height at bank and "key area"	BDNF/BLM riparian standards (Bengeyfield and Svoboda, 1998)
Long-term riparian area recovery	• Photo points • PFC/NRCS Riparian Assessment (every 5-10 yrs) • Vegetation Survey (transects perpendicular to stream and spanning immediate floodplain) every 5-10 years o Strip transects- Daubenmire 20cm x 50cm grid or point line transects	Harrelson et al., 1994; Bauer and Burton, 1993; NRCS, 2001 Stream Assessment Protocols
Streambank stability	Greenline including bare ground, bank stability, woody species regeneration (every 3-5 years)	Modified from Winward, 2000
Channel stability	Cross-sectional area, with % fines/ embeddedness • Channel cross-section survey • Wolman pebble count • Grid or McNeil core sample	Rosgen, 1996; Harrelson et al., 1994
Aquatic habitat condition	• Aquatic macroinvertebrate sampling • Pool quality • R1/R4 aquatic habitat survey	DEQ biomonitoring protocols; Hankin and Reeves, 1988; USFS 1997 R1R4 protocols
General stream corridor condition	EMAP/Riparian Assessment (every 5-10 yrs)	NRCS 2001 Stream Assessment Protocols; U.S. EPA 2003.

11.2.3.4 Other Restoration Activities

This TMDL assessment has revealed the importance of beaver to stream systems within the Upper and North Fork Big Hole River TPA. Beavers are important for managing water and sediment runoff and allowing recovery of riparian zones. Re-establishing populations in some areas may be an important tool for restoring natural channel dynamics and healthy riparian zones. Alternatively, beavers may cause problems by moving into irrigation networks and may need to be managed closely because of this issue. Monitoring is needed to identify areas that can support beaver populations, define habitat requirements to be able to assess likelihood of reintroduction success in potential sites, and determine positive and negative influences of beaver reintroduction on channel stability, fish habitat, water quality and quantity, riparian habitat, and aquatic and terrestrial wildlife. Specific monitoring needs will depend on the nature of reintroduction efforts and site-specific requirements.

11.2.3.5 Watershed-Scale Monitoring

Monitoring should be conducted at a watershed scale over several years to determine 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 also a long-term process. Long-term monitoring should be an understood component of any restoration effort.

Trends in water quality are difficult to define, and even more difficult to relate directly to restoration or other changes in management, due to the natural high variability in water quality conditions. Improvements in water quality or aquatic habitat resulting from restoration activities on listed streams are most likely to be evident in increases in instream flow, changes in communities and distribution of fish and other bioindicators, improvements in bank stability and riparian habitat, changes in channel cumulative width/depths, fine sediment deposition and channel substrate embeddedness. 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 budgetary and time constraints. Long term water quality assessment should occur at the USGS Wisdom gage station to document long term trends in temperature, nutrients and potentially Total Suspended Solids (TSS).

SECTION 12.0
STAKEHOLDER AND PUBLIC COMMENTS

Stakeholder and public involvement is a component of TMDL planning efforts supported by EPA guidelines and Montana State Law. Public comment on the Upper and North Fork Big Hole River TMDLs involved two components. First, stakeholders and a technical advisory group (including private landowners, conservation groups, and agency representatives) were kept abreast of the TMDL process through periodic meetings, and were provided opportunities to review and comment on interim technical documents which ultimately became appendices to the final TMDL document. The stakeholders and a technical advisory group also were allowed a stakeholder draft comment timeframe during which the draft document was posted on the Big Hole Watershed Committee's website until the public comment draft was posted for the public comment period on DEQ's website. In addition, presentations about the draft TMDL document were provided to the following groups:

- Technical Advisory Group – Divide, MT, November, 6th, 2008
- Stakeholder Feedback – Wisdom, MT, November, 11th , 2008

The second component of public involvement was a public comment period. This public review period was initiated on December 15th, 2008 and extended through January 16th, 2009. A public meeting on December 10th, 2008 in Wisdom, Montana provided an overview of the Upper and North Fork Big Hole River TMDLs and Watershed Water Quality Planning Framework document. The meeting provided an opportunity to solicit public input and comments on the plan. This meeting and the opportunity to provide public comment on the draft document were advertised via a press release by DEQ and was included in a number of local newspapers. Copies of the main document were available at the Beaverhead County Conservation District, Wisdom Post Office, Jackson Post Office, the Montana State Library, and via the internet on DEQ's web page or via direct communication with the DEQ project manager.

Appendix L includes a summary of the public comments received and the DEQ response to these comments. The original comment letters are located in the project files at DEQ and may be reviewed upon request.

DEQ also provides an opportunity for public comment during the biennial review of the Montana's Integrated Water Quality Report that includes the 303(d) List. This includes public meetings and opportunities to submit comments either electronically or through traditional mail. DEQ announces the public comment opportunities through several media including press releases and the Internet.

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APPENDIX A
SEDIMENT CONTRIBUTION FROM HILLSLOPE EROSION

Introduction
Upland sediment loading due to hillslope erosion was modeled using the Universal Soil Loss Equation (USLE), and sediment delivery to the stream was predicted using a sediment delivery ratio. This model provided an assessment of existing sediment loading from upland sources and an assessment of potential sediment loading through the application of Best Management Practices (BMPs). For this evaluation the primary BMP evaluated includes the modification in upland management practices. When reviewing the results of the upland sediment load model it is important to note that a significant portion of the remaining sediment loads after BMPs in areas with grazing and/or silvicultural land-uses is also a component of the "natural upland load". However, the assessment methodology didn't differentiate between sediment loads with all reasonable BMPs and "natural" loads.

A list of land cover classifications used in the USLE model is presented in **Table A-1**, along with a description of which land-use was associated with each cover type for the purposes of sediment source assessment and load allocations.

Table A-1. Land Cover Classifications for the USLE Model.

Land Cover Classifications	Land-use / Sediment Source
Bare Rock/Sand/Clay	Natural Source
Deciduous Forest	Natural Source
Evergreen Forest	Natural Source
Mixed Forest	Natural Source
Woody Wetlands	Natural Source
Logging	Silviculture
Grasslands/Herbaceous	Agriculture
Shrubland	Agriculture
Pasture/Hay	Agriculture
Small Grains	Agriculture
Fire	Fire

Universal Soil Loss Equation (USLE)
The general form of the USLE has been widely used for erosion prediction in the U.S. and is presented in the National Engineering Handbook (1983) as:

(1) $A = RK(LS)CP$ (in tons acre^{-1} year^{-1})

where soil loss (A) is a function of the rainfall erosivity index (R), soil erodibility factor (K), overland flow slope and length (LS), crop management factor (C), and conservation practice factor (P) (Wischmeier and Smith 1978, Renard et al. 1991). The USLE estimates average soil loss from sheet and rill erosion but does not estimate soil loss from gully erosion. USLE was selected for the upper Big Hole watershed due to its relative simplicity, ease in parameterization, and the fact that it has been integrated into a number of other erosion prediction models. These include: (1) the Agricultural Nonpoint Source Model (AGNPS), (2) Areal Nonpoint Source Watershed Environment Response Simulation Model (ANSWERS), (3) Erosion Productivity Impact Calculator (EPIC), (4) Generalized Watershed Loading Functions (GWLF), and (5) the Soil Water Assessment Tool (SWAT) (Doe, 1999). A detailed description of the general USLE model parameters is presented below.

The R-factor is an index that characterizes the effect of raindrop impact and rate of runoff associated with a rainstorm. It is a summation of the individual storm products of the kinetic energy in rainfall (hundreds of ft-tons acre-1 year-1) and the maximum 30-minute rainfall intensity (inches hour-1). The total kinetic energy of a storm is obtained by multiplying the kinetic energy per inch of rainfall by the depth of rainfall during each intensity period.

The K-factor or soil erodibility factor indicates the susceptibility of soil to resist erosion. It is derived by measurement of soil particle size (texture), percent organic matter, structure, and permeability. It is a measure of the average soil loss (tons acre-1 hundreds of ft-tons-1 per acre of rainfall intensity) from a particular soil in continuous fallow. The K-factor is based on experimental data from the standard SCS erosion plot that is 72.6 ft long with uniform slope of 9 percent.

The LS-factor is a function of the slope and overland flow length of the eroding slope or cell. For the purpose of computing the LS-value, slope is defined as the average land surface gradient. The flow length refers to the distance between where overland flow originates and runoff reaches a defined channel or depositional zone. According to McCuen, (1998), flow lengths are seldom greater than 400 or shorter than 20 feet.

The C-factor or crop management factor is the ratio of the soil eroded from a specific type of cover to that from a clean-tilled fallow under identical slope and rainfall. It integrates a number of factors that effect erosion including vegetative cover, plant litter, soil surface, and land management. The original C-factor of the USLE was experimentally determined for agricultural crops and has since been modified to include rangeland and forested cover. It is now referred to as the vegetation management factor (VM) for non-agricultural settings (Brooks, 1997).

Three different kinds of effects are considered in determination of the VM-factor. These include: (1) canopy cover effects, (2) effects of low-growing vegetal cover, mulch, and litter, and (3) rooting structure. A set of metrics has been published by the Soil Conservation Service (SCS) for estimation of the VM-factors for grazed and undisturbed woodlands, permanent pasture, rangeland, and idle land. Although these are quite helpful for the upper Big Hole watershed, Brooks (1997) cautions that more work has been carried out in determining the agriculturally based C-factors than rangeland/forest VM-factors. Because of this, the results of the interpretation should be used with discretion.

The P-factor (conservation practice factor) is a function of the interaction of the supporting land management practice and slope. It incorporates the use of erosion control practices such as strip-cropping, terracing, and contouring, and is applicable only to agricultural lands. Values of the P-factor compare straight-row (up-slope down-slope) farming practices with that of certain agriculturally-based conservation practices.

Modeling Approach
Sediment delivery from hillslope erosion was estimated using a Universal Soil Loss Equation (USLE) based model to predict soil loss, along with a sediment delivery ratio, (SDR) to predict sediment delivered to the stream. This USLE based model is implemented as a watershed scale, grid format, GIS model using ArcView v 9.0 GIS software.

Desired results from the modeling effort include the following: (1) annual sediment load from each of the water quality limited segments on the state's 303(d) List, and (4) the mean annual source distribution from each land category type. Based on these considerations, a GIS-modeling approach (USLE 3-D) was formulated to facilitate database development and manipulation, provide spatially explicit output, and supply output display for the modeling effort.

Modeling Scenarios
Two upland management scenarios were proposed as part of the Upper Big Hole River modeling project. They include: (1) an existing condition scenario that considers the current land use cover and management practices in the watershed and (2) an improved grazing and cover management scenario.

Erosion was differentiated into two source categories for each scenario: (1) natural erosion that occurs on the time scale of geologic processes and (2) anthropogenic erosion that is accelerated by human-caused activity. A similar classification is presented as part of the National Engineering Handbook Chapter 3 - Sedimentation (USDA, 1983). Differentiation is necessary for TMDL planning.

Data Sources
The USLE-3D model was parameterized using a number of published data sources. These include information from: (1) USGS, (2) Spatial Climate Analysis Service (SCAS), and (3) Soil Conservation Service (SCS). Additionally, local information regarding specific land use management and cropping practices was acquired from the Montana Agricultural Extension Service and the Natural Resource Conservation Service (NRCS). Specific GIS coverages used in the modeling effort included the following:

<u>R – Rainfall factor</u>. Grid data of this factor was obtained from the NRCS, and is based on Parameter-elevation Regressions on Independent Slopes Model (PRISM) precipitation data. PRISM precipitation data is derived from weather station precipitation records, interpolated to a gridded landscape coverage by a method (developed by the Spatial Climate Analysis Service of Oregon State University) which accounts for the effects of elevation on precipitation patterns.

<u>K – Soil erodibility factor</u>. Polygon data of this factor was obtained from the NRCS General Soil Map (STATSGO) database. The USLE K factor is a standard component of the STATSGO soil survey. STATSGO soils polygon data were summarized and interpolated to grid format for this analysis.

<u>LS – Slope length and slope factors</u>. These factors were derived from 30m USGS digital elevation model (DEM) grid data, interpolated to a 10m pixel.

C – Cropping factor. This factor was estimated using the National Land Cover Dataset (NLCD), using C-factor interpretations provided by the NRCS and refined by Montana DEQ using SCS C-factor tables (Brooks et al. 1997). C-factors are intended to be conservatively representative of conditions in the Big Hole valley.

P – Management practices factor. This factor was set to 1, as consultation with the NRCS State Agronomist suggests that this value is the most appropriate representation of current management practices in the Big Hole valley (i.e. no use of contour plowing, terracing, etc).

Method

An appropriate grid for each factors' values was created, giving full and appropriate consideration to proper stream network delineation, grid cell resolution, etc. A computer model was built using ArcView Model Builder to derive the five factors from model inputs, multiply the five factors and arrive at a predicted sediment production for each grid cell. The model also derived a sediment delivery ratio for each cell, and reduced the predicted sediment production by that factor to estimate sediment delivered to the stream network.

Specific parameterization of the USLE factors was performed as follows:

Upper Big Hole DEM

The digital elevation model (DEM) for the upper Big Hole watershed (**Figure A-2**) was the foundation for developing the LS factor, for defining the extent of the bounds of the analysis area (the upper Big Hole watershed), and for delineating the area within the outer bounds of the analysis for which the USLE model is not valid (i.e. the concentrated flow channels of the stream network). The USGS 30m DEM (level 2) for the upper Big Hole was used for these analyses. First the DEM was interpolated to a 10m analytic grid cell to render the delineated stream network more representative of the actual size of upper Big Hole watershed streams and to minimize resolution dependent stream network anomalies. The resulting interpolated 10m was then subjected to standard hydrologic preprocessing, including the filling of sinks to create a positive drainage condition for all areas of the watershed.

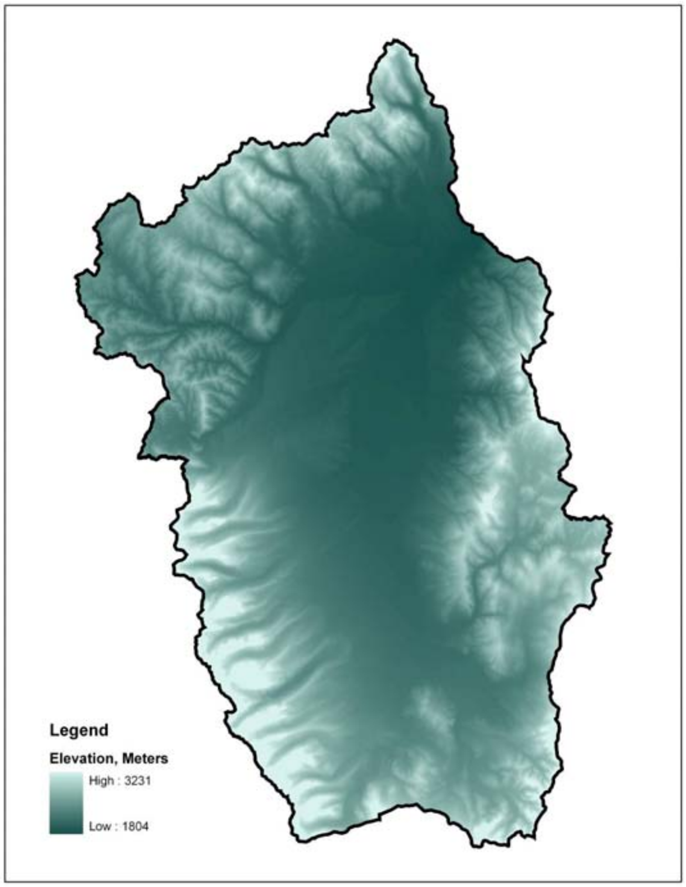

Figure A-1. Digital Elevation Model (DEM) of the upper Big Hole watershed, prepared for hydrologic analysis.

R-Factor

The rainfall and runoff factor grid was prepared by the Spatial Climate Analysis Service of Oregon State University, at 4 km grid cell resolution. For the purposes of this analysis, the SCAS R-factor grid was reprojected to Montana State Plane Coordinates (NAD83, meters), resampled to a 10m analytic cell size and clipped to the extent of the upper Big Hole watershed, to match the project's standard grid definition. (**Figure A-2**)

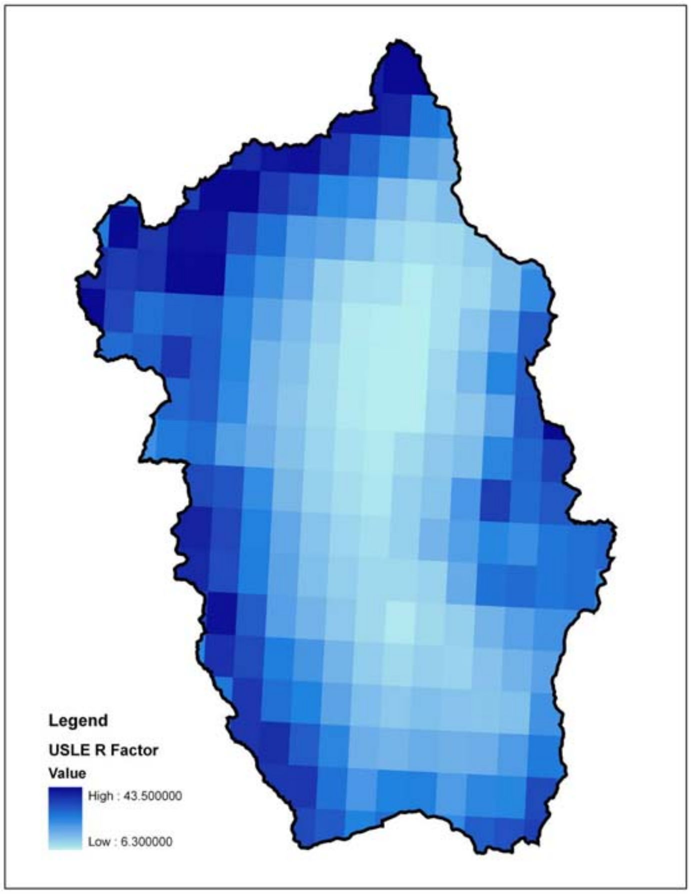

Figure A-2. ULSE R factor for the upper Big Hole Watershed.

K-Factor

The soil erodibility factor grid was compiled from 1:250K STATSGO data, as published by the NRCS. STATSGO database tables were queried to calculate a component weighted K value for all surface layers, which was then summarized by individual map unit. The map unit K values were then joined to a GIS polygon coverage of the STATSGO map units, and the polygon coverage was converted to a 10m analytic grid for use in this analysis. (**Figure A-3**)

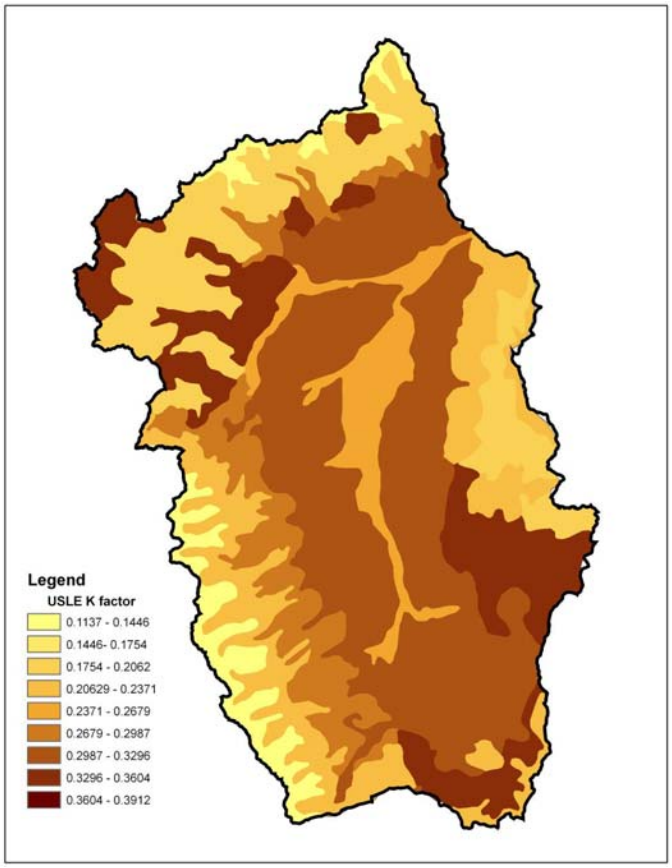

Figure A-3. ULSE K factor for the Upper Big Hole Watershed.

<u>LS- Factor</u>
The equation used for calculating the slope length and slope factor was that given in the updated definition of USLE, as published in USDA handbook #537:

$$LS = (\lambda/72.6)^m\ (65.41 \sin^2\theta + 4.56 \sin\theta + 0.065)$$

Where:

λ = slope length in feet. This value was determined by applying GIS based surface analysis procedures to the upper Big Hole watershed DEM, calculating total upslope length for each 10m grid cell, and converting the results to feet from meters. In accordance with research that indicates that, in practice, the slope length rarely exceeds 400 ft, λ was limited to that maximum value.

θ = cell slope as calculated by GIS based surface analysis procedures from the upper Big Hole watershed DEM

m = 0.5 if percent slope of the cell >= 5
= 0.4 if percent slope of the cell >= 3.5 AND < 5
= 0.3 if percent slope of the cell >= 1 AND < 3.5
= 0.2 if percent slope of the cell < 1

The LS factor grid was calculated from individual grids computed for each of these sub factors, using a simple ArcView Model Builder script.

C-Factor

The cover management factor of the USLE reflects the varying degree of erosion protection that results from different cover types. It integrates a number of factors including vegetative cover, plant litter, soil surface, and land management. For the purpose of this study, the C-factor is the only USLE parameter that can be altered by the influence of human activity. Based on this, C-factors were estimated for the existing condition and improved management scenarios (**Table A-2**). The C-factor change for agricultural cover types between management scenarios corresponds to increases in the percent of land cover that are achievable through the application of various best management practices (**Table A-3**). For natural sources (i.e. bare rock, deciduous forest, and evergreen forest), the C-factor is the same for both scenarios. A C-factor slightly higher than deciduous/evergreen forest was used for logged areas because logging intensity within the watershed is generally low and because practices, such as riparian clearcutting, that tend to produce high sediment yields have not been used since at least 1991, when the MT Streamside Management Zone (SMZ) law was enacted. Additionally, the USLE model is intended to reflect long-term average sediment yield, and while a sediment pulse typically occurs in the first year after logging, sediment production after the first year rapidly declines (Rice et al. 1972; Elliot and Robichaud 2001; Elliot 2006). The logging C-factor is the same for both management scenarios to indicate that logging will continue sporadically on public and private land within the watershed and will produce sediment at a rate slightly higher than an undisturbed forest. This is not intended to imply that additional best management practices beyond those in the SMZ law should not be used for logging activities. Because the Mussigbrod fire was in 2000 and the rate of erosion rapidly declines after the first year as vegetation re-establishes (Elliot and Robichaud 2001), the existing C-factor corresponds to the existing C-factor used in logged areas, and the improved C-factor varies depending on the improved C-factor for the underlying land cover type (see **Table A-2**).

C-factors were defined spatially through use of a modified version of the Anderson land cover classification (1976) and the 1992 30m Landsat Thematic Mapper (LTM) multi-spectral imaging (NLDC, 1992) (**Figure A-4**). C-factor values were assigned globally to each land type and range from 0.001 to 1.0. These data were reprojected to Montana State plane projection/coordinate system, and resampled to the standard 10m grid. No field efforts were initiated as part of this study to refine C-factor estimation for the watershed.

Table A-2. Upper Big Hole River C-Factor; Existing and improved management conditions.

NLCD Code	Description	C-Factor	
		Existing Condition	Improved Management Condition
31	Bare Rock/Sand/Clay	0.001	0.001
41	Deciduous Forest	0.003	0.003
42	Evergreen Forest	0.003	0.003
43	Mixed Forest	0.003	0.003
91	Woody Wetlands	0.0001	0.0001
51	Shrubland	0.046	0.031
71	Grasslands Herbaceous	0.042	0.035
81	Pasture /Hay	0.020	0.013
83	Small Grains	0.240	0.015
N/A	Logging	0.006	0.006
N/A	Fire	0.006	Variable*

*Improved C factor depends on the underlying land cover type

Table A-3. Changes in percent ground cover for agricultural land cover types between existing and improved management conditions.

Land Cover	Existing % ground cover	Improved % ground cover
Shrubland	55	65
Grasslands Herbaceous	55	65
Pasture /Hay	65	75
Small Grains	20	40

<u>NLCD – Landcover</u>

In general, the land use classification of the NLCD was accepted as is, without ground truthing of original results or correction of changes over the time since the NLCD image was taken. Given that we are looking for watershed and subwatershed scale effects, this was considered to be a reasonable assumption, given the relative simplicity of the land use mix in the Big Hole valley, and the relative stability of that land use over the 14 years since the Landsat image that the NLCD is based on was shot. Two adjustments were made to the NLCD, however. The first adjustment was to quantify the amount of logging that has occurred since 1992, and to also identify areas that are reforesting over that same period. The other adjustment was to account for change in land cover due to the Mussigbrod fire of 2000.

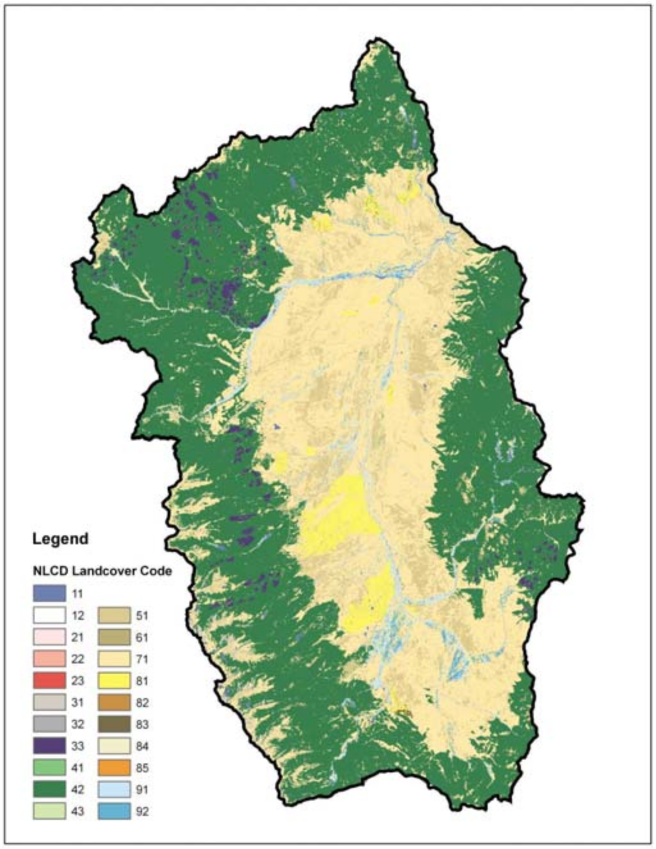

Figure A-4. NLCD Landcover for the Upper Big Hole Watershed.

As with other land uses in the valley, logging is a stable land use, but it is a land use that causes a land cover change that may effect sediment production. Similarly wildland fire, while not a landuse per se, is affected by land management decisions and may cause a change in vegetation cover. Adjustment for logging and reforestation was accomplished by comparing the 1992 NLCD grid for the upper Big Hole watershed with the 2005 NAIP aerial photography. Areas which were coded as a forest type (41 or 42) on the NLCD were recoded to 'logged' if:

- They appeared to be otherwise (typically bare ground, grassland, or shrubland) on the NAIP photos, and
- There were indications of indicated logging activity (proximity to forest or logging roads, appearance of stands, etc).

Adjustment for the land cover change caused by the Mussigbrod fire was accomplished by using the USFS mapping of the fire intensity within the burned area. Fire intensities of 'moderate mosaic' or above were considered to be land cover changing, and it was further assumed that these areas will eventually return (through natural processes or management activities) to their pre-fire condition.

Sediment Delivery Ratio

A sediment delivery ratio (SDR) factor was created for each grid cell, based on the relationship between the distance from the delivery point to the stream established by Dube, Megahan &

McCalmon in their development of the WARSEM road sediment model for the State of Washington. This relationship was developed by integrating the results of several previous studies, (principally those of Megehan and Ketchison), which examined sediment delivery to streams downslope of forest roads. They found that the proportion of sediment production that is ultimately delivered to streams declines with distance from the stream (**Table A-4**) with the balance of the sediment being deposited between the point of production and the stream. We believe the use of this relationship to develop a SDR for a USLE based model is a conservative (i.e. tending toward the high end of the range of reasonable values) estimate of sediment delivery from hillslope erosion, especially in light of the fact that the USLE methodology does not account for gully erosion. The SDR factor was applied to the results of the USLE model to estimate sediment delivered from hill slope sources, by calculating the distance from each cell to the nearest stream channel, and multiplying the sediment production of that cell by the corresponding distance based percentage of delivery.

Table A-4. The percent of sediment delivered by distance from a water body.

Distance from Culvert (ft)	Percent of Total Eroded Sediment Delivered
0	100
35	70
70	50
105	35
140	25
175	18
210	10
245	4
280	3
315	2
350	1

Although the SDR factor accounts for the distance of sediment production cells from the stream channel, it does not account for riparian condition and the ability of riparian vegetation to filter out sediment and prevent it from entering the stream. Depending on the vegetation type and buffer width, healthy riparian buffers can remove anywhere from 50-90 percent of sediment (Castelle and Johnson 2000; Hook 2003; MDEQ 2007). Therefore, the USLE model used for source assessment may have overestimated existing loads and underestimated potential reductions due to hillslope erosion.

Results

Figures A-5 and **A-6** present the USLE based hillslope model's prediction of existing and potential conditions for the upper Big Hole watershed. **Table A-5** contains the estimated existing and potential sediment load from hillslope erosion for each 6th code HUC and the upper Big Hole watershed, and it also contains loads normalized by the contributing watershed area. **Table A-6** contains the estimated existing and potential sediment load from hillslope erosion for the upper Big Hole watershed and broken out by 6th code HUC and existing land cover type.

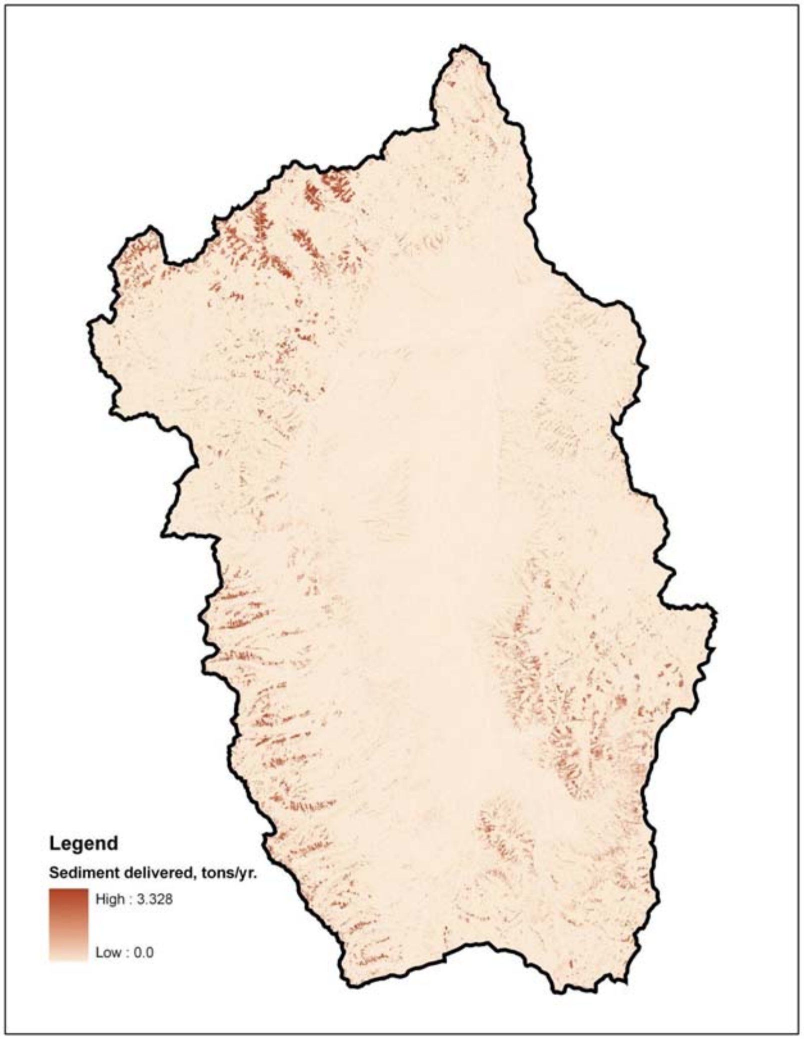

Figure A-5. Estimated sediment delivery from hill slopes, existing conditions.

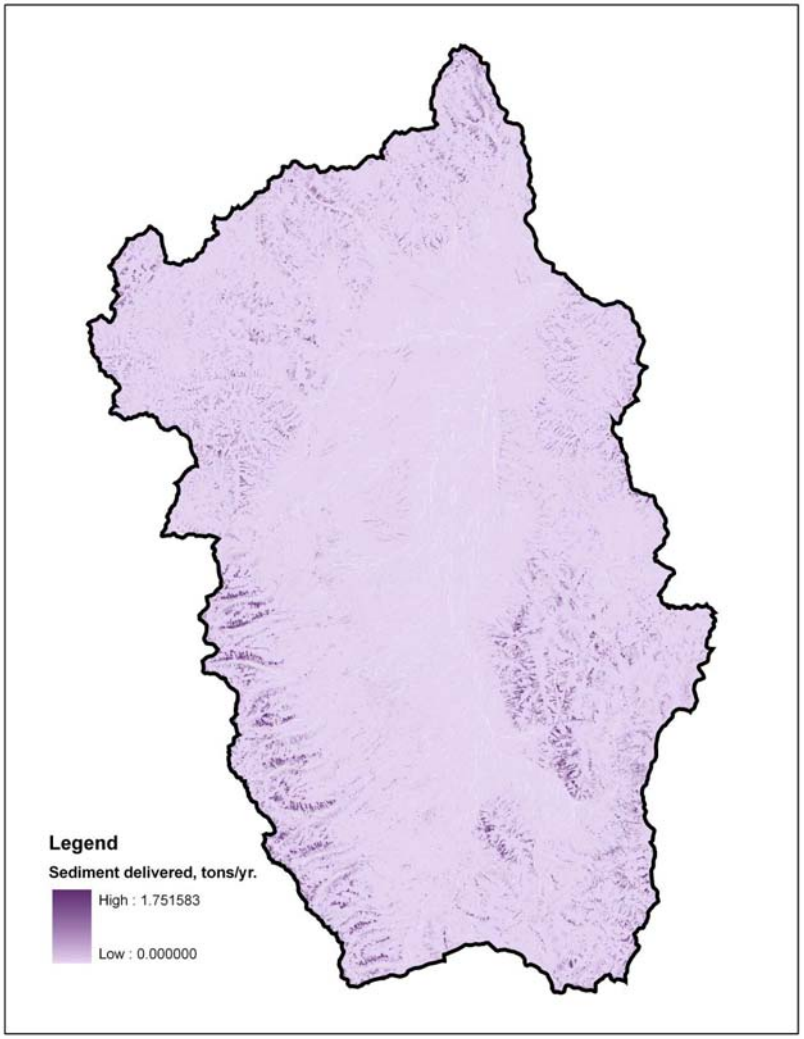

Figure A-6. Estimated sediment delivery from hill slopes, BMP conditions.

Table A-5. Total and normalized existing and potential sediment loads from upland erosion for each 6th code HUC (Sub-Watershed) and for the upper Big Hole watershed (i.e. all HUCs). The upper Big Hole watershed is bolded.

6th Code HUC Subwatershed	Acres	Existing Load (tons/yr)	Potential Load (tons/yr)	Normalized Existing Load (tons/acre/yr)	Normalized Potential Load (tons/acre/yr)
Andrus Creek	12658	1250	1047	0.099	0.083
Berry Creek	9132	859	698	0.094	0.076
Big Swamp Creek	15256	1451	1170	0.095	0.077
Big Hole River-Big Swamp Creek	20532	524	423	0.026	0.021
Big Hole River-McVey Homestead	17216	184	146	0.011	0.009
Big Hole River-Saginaw Creek	14824	1085	756	0.073	0.051
Big Hole River-Spring Creek	20144	983	761	0.049	0.038
Big Hole River-Squaw Creek	8565	168	130	0.020	0.015
Big Hole River-Wisdom	17787	563	446	0.032	0.025
Big Lake Creek	28043	2246	1826	0.080	0.065
Bull Creek	30605	3067	2520	0.100	0.082
Doolittle Creek	13822	620	536	0.045	0.039
Englejard Creek	17476	1081	871	0.062	0.050
Fox Creek	7805	1062	870	0.136	0.111
Francis Creek	16143	584	502	0.036	0.031
Headwaters Big Hole River	20967	2237	1802	0.107	0.086
Howell Creek	12859	505	432	0.039	0.034
Johnson Creek	22269	1115	873	0.050	0.039
Joseph Creek	8004	322	301	0.040	0.038
Little Lake Creek	14775	1375	1108	0.093	0.075
Lower Governor Creek	17789	1166	911	0.066	0.051
Lower Rock Creek	10099	107	84	0.011	0.008
Lower Trail Creek	16558	729	655	0.044	0.040
Lower Warm Springs Creek	29047	2756	2248	0.095	0.077
May Creek	9839	414	387	0.042	0.039
McVey Creek	9426	369	310	0.039	0.033
Miner Creek	18088	2332	1892	0.129	0.105
Mussigbrod Creek	16207	1049	809	0.065	0.050
North Fork Big Hole River	26228	292	234	0.011	0.009
Old Tim Creek	14172	695	606	0.049	0.043
Pine Creek	3938	352	289	0.089	0.073
Pintlar Creek	17779	1513	1290	0.085	0.073
Plimpton Creek	28627	929	789	0.032	0.028
Ruby Creek	23915	1465	1272	0.061	0.053
Schulz creek	2383	80	54	0.034	0.023
Stanley Creek	11772	366	311	0.031	0.026
Steel Creek	17968	714	609	0.040	0.034
Swamp Creek	31427	1634	1312	0.052	0.042
Tie Creek	19561	854	759	0.044	0.039
Upper Governor Creek	10763	600	498	0.056	0.046
Upper Rock Creek	27615	1955	1606	0.071	0.058
Upper Trail Creek	16149	805	644	0.050	0.040
Upper Warm Springs Creek	12404	386	331	0.031	0.027

Table A-5. Total and normalized existing and potential sediment loads from upland erosion for each 6th code HUC (Sub-Watershed) and for the upper Big Hole watershed (i.e. all HUCs). The upper Big Hole watershed is bolded.

6th Code HUC Subwatershed	Acres	Existing Load (tons/yr)	Potential Load (tons/yr)	Normalized Existing Load (tons/acre/yr)	Normalized Potential Load (tons/acre/yr)
West Fork Ruby Creek	10202	570	499	0.056	0.049
Upper Big Hole Watershed	**730837**	**43414**	**35618**	**0.059**	**0.049**

Table A-6. Existing and potential sediment loads from upland erosion by land cover type for each 6th code HUC (Sub-Watershed) and for the upper Big Hole watershed (i.e. all HUCs). The upper Big Hole watershed is bolded.

Subwatershed	Land Cover Classification	Existing Sediment (tons/yr)	Potential Sediment (tons/yr)
Andrus Creek	Evergreen Forest	292	292
	Grasslands/Herbaceous	684	570
	Shrubland	274	185
Andrus Creek Total		1250	1047
Berry Creek	Bare Rock/Sand/Clay	5	5
	Evergreen Forest	153	153
	Grasslands/Herbaceous	425	354
	Shrubland	275	186
Berry Creek Total		859	698
Big Swamp Creek	Bare Rock/Sand/Clay	9	9
	Evergreen Forest	216	216
	Grasslands/Herbaceous	654	545
	Pasture/Hay	1	<1
	Shrubland	525	354
	Logging	46	46
Big Swamp Creek Total		1451	1170
Big Hole River-Big Swamp Creek	Evergreen Forest	77	77
	Grasslands/Herbaceous	286	239
	Pasture/Hay	21	14
	Shrubland	139	94
Big Hole River-Big Swamp Creek Total		524	423
Big Hole River-McVey Homestead	Evergreen Forest	2	2
	Grasslands/Herbaceous	143	119
	Pasture/Hay	1	<1
	Shrubland	38	26
Big Hole River-McVey Homestead Total		184	146
Big Hole River-Saginaw Creek	Evergreen Forest	114	114
	Grasslands/Herbaceous	521	434
	Logging	6	6
	Pasture/Hay	13	8
	Shrubland	273	184
	Small Grains	160	10
Big Hole River-Saginaw Creek Total		1085	756

Table A-6. Existing and potential sediment loads from upland erosion by land cover type for each 6th code HUC (Sub-Watershed) and for the upper Big Hole watershed (i.e. all HUCs). The upper Big Hole watershed is bolded.

Subwatershed	**Land Cover Classification**	**Existing Sediment (tons/yr)**	**Potential Sediment (tons/yr)**
Big Hole River-Spring Creek	Evergreen Forest	23	23
	Grasslands/Herbaceous	554	461
	Logging	8	8
	Pasture/Hay	14	9
	Shrubland	383	258
	Woody Wetlands	1	1
Big Hole River-Spring Creek Total		983	761
Big Hole River-Squaw Creek	Evergreen Forest	4	4
	Grasslands/Herbaceous	99	83
	Shrubland	65	44
Big Hole River-Squaw Creek Total		168	130
Big Hole River-Wisdom	Evergreen Forest	27	27
	Grasslands/Herbaceous	361	301
	Shrubland	176	118
Big Hole River-Wisdom Total		563	446
Big Lake Creek	Bare Rock/Sand/Clay	5	5
	Evergreen Forest	351	351
	Grasslands/Herbaceous	1194	995
	Pasture/Hay	17	11
	Shrubland	661	445
	Logging	18	18
Big Lake Creek Total		2246	1826
Bull Creek	Emergent Herbaceous Wetlands	2	2
	Evergreen Forest	202	202
	Grasslands/Herbaceous	2293	1908
	Logging	70	70
	Shrubland	499	336
	Woody Wetlands	1	1
Bull Creek Total		3067	2520
Doolittle Creek	Evergreen Forest	246	246
	Grasslands/Herbaceous	239	199
	Shrubland	134	91
Doolittle Creek Total		620	536
Englejard Creek	Bare Rock/Sand/Clay	4	4
	Evergreen Forest	153	153
	Grasslands/Herbaceous	581	484
	Pasture/Hay	2	<1
	Shrubland	342	230
Englejard Creek Total		1081	871

Table A-6. Existing and potential sediment loads from upland erosion by land cover type for each 6th code HUC (Sub-Watershed) and for the upper Big Hole watershed (i.e. all HUCs). The upper Big Hole watershed is bolded.

Subwatershed	Land Cover Classification	Existing Sediment (tons/yr)	Potential Sediment (tons/yr)
Fox Creek	Evergreen Forest	190	190
	Grasslands/Herbaceous	574	478
	Shrubland	296	200
	Woody Wetlands	1	1
Fox Creek Total		1062	870
Francis Creek	Evergreen Forest	186	186
	Grasslands/Herbaceous	291	242
	Logging	6	6
	Shrubland	100	67
Francis Creek Total		584	502
Headwaters Big Hole River	Bare Rock/Sand/Clay	4	4
	Evergreen Forest	439	439
	Grasslands/Herbaceous	945	787
	Shrubland	849	572
Headwaters Big Hole River Total		2237	1802
Howell Creek	Evergreen Forest	219	219
	Grasslands/Herbaceous	133	111
	Pasture/Hay	2	1
	Shrubland	149	100
	Small Grains	2	<1
Howell Creek Total		505	432
Johnson Creek	Evergreen Forest	343	343
	Fire	318	168
	Grasslands/Herbaceous	266	220
	Logging	50	50
	Shrubland	138	93
Johnson Creek Total		1115	873
Joseph Creek	Evergreen Forest	230	230
	Grasslands/Herbaceous	35	29
	Shrubland	47	32
	Logging	6	6
	Woody Wetlands	4	4
Joseph Creek Total		322	301
Little Lake Creek	Bare Rock/Sand/Clay	10	10
	Evergreen Forest	179	179
	Grasslands/Herbaceous	748	623
	Shrubland	438	295
Little Lake Creek Total		1375	1108

Table A-6. Existing and potential sediment loads from upland erosion by land cover type for each 6th code HUC (Sub-Watershed) and for the upper Big Hole watershed (i.e. all HUCs). The upper Big Hole watershed is bolded.

Subwatershed	**Land Cover Classification**	**Existing Sediment (tons/yr)**	**Potential Sediment (tons/yr)**
Lower Governor Creek	Emergent Herbaceous Wetlands	1	1
	Grasslands/Herbaceous	779	649
	Shrubland	385	260
	Woody Wetlands	1	1
Lower Governor Creek Total		1166	911
Lower Rock Creek	Grasslands/Herbaceous	77	64
	Shrubland	29	20
Lower Rock Creek Total		107	84
Lower Trail Creek	Evergreen Forest	398	398
	Grasslands/Herbaceous	95	79
	Logging	55	55
	Shrubland	179	121
	Woody Wetlands	2	2
Lower Trail Creek Total		729	655
Lower Warm Springs Creek	Deciduous Forest	1	1
	Emergent Herbaceous Wetlands	2	2
	Evergreen Forest	488	488
	Grasslands/Herbaceous	1398	1164
	Logging	14	14
	Shrubland	844	569
	Woody Wetlands	10	10
Lower Warm Springs Creek Total		2756	2248
May Creek	Evergreen Forest	308	308
	Grasslands/Herbaceous	47	39
	Shrubland	60	40
May Creek Total		414	387
McVey Creek	Evergreen Forest	100	100
	Grasslands/Herbaceous	180	150
	Shrubland	89	60
McVey Creek Total		369	310
Miner Creek	Bare Rock/Sand/Clay	13	13
	Evergreen Forest	257	257
	Grasslands/Herbaceous	1460	1217
	Pasture/Hay	2	1
	Shrubland	600	404
Miner Creek Total		2332	1892
Mussigbrod Creek	Evergreen Forest	303	303
	Fire	317	168
	Grasslands/Herbaceous	297	247
	Logging	5	5
	Shrubland	127	85
Mussigbrod Creek Total		1049	809

Table A-6. Existing and potential sediment loads from upland erosion by land cover type for each 6th code HUC (Sub-Watershed) and for the upper Big Hole watershed (i.e. all HUCs). The upper Big Hole watershed is bolded.

Subwatershed	Land Cover Classification	Existing Sediment (tons/yr)	Potential Sediment (tons/yr)
North Fork Bighole River	Evergreen Forest	26	26
	Grasslands/Herbaceous	193	161
	Logging	6	6
	Pasture/Hay	5	3
	Shrubland	58	39
	Small Grains	4	<1
North Fork Bighole River Total		292	234
Old Tim Creek	Evergreen Forest	336	336
	Grasslands/Herbaceous	151	126
	Shrubland	194	131
	Logging	13	13
Old Tim Creek Total		695	606
Pine Creek	Evergreen Forest	141	141
	Grasslands/Herbaceous	33	28
	Shrubland	178	120
Pine Creek Total		352	289
Pintlar Creek	Evergreen Forest	520	520
	Fire	10	5
	Grasslands/Herbaceous	638	532
	Logging	1	1
	Shrubland	344	232
Pintlar Creek Total		1513	1290
Plimpton Creek	Evergreen Forest	290	290
	Fire	2	<1
	Grasslands/Herbaceous	452	377
	Logging	1	1
	Pasture/Hay	3	2
	Shrubland	177	120
	Small Grains	4	<1
Plimpton Creek Total		929	789
Ruby Creek	Evergreen Forest	571	571
	Grasslands/Herbaceous	573	477
	Logging	21	21
	Shrubland	296	199
	Woody Wetlands	4	4
Ruby Creek Total		1465	1272
Schulz creek	Evergreen Forest	6	6
	Fire	56	30
	Shrubland	1	1
	Logging	18	18
Schulz creek Total		80	54

Table A-6. Existing and potential sediment loads from upland erosion by land cover type for each 6th code HUC (Sub-Watershed) and for the upper Big Hole watershed (i.e. all HUCs). The upper Big Hole watershed is bolded.

Subwatershed	Land Cover Classification	Existing Sediment (tons/yr)	Potential Sediment (tons/yr)
Stanley Creek	Evergreen Forest	91	91
	Grasslands/Herbaceous	223	186
	Logging	1	1
	Pasture/Hay	1	<1
	Shrubland	50	34
Stanley Creek Total		366	311
Steel Creek	Evergreen Forest	275	275
	Grasslands/Herbaceous	237	197
	Logging	1	1
	Shrubland	201	136
Steel Creek Total		714	609
Swamp Creek	Bare Rock/Sand/Clay	3	3
	Evergreen Forest	201	201
	Grasslands/Herbaceous	893	744
	Logging	6	6
	Shrubland	531	358
Swamp Creek Total		1634	1312
Tie Creek	Evergreen Forest	436	436
	Fire	28	15
	Grasslands/Herbaceous	126	104
	Logging	79	79
	Shrubland	186	125
Tie Creek Total		854	759
Upper Governor Creek	Evergreen Forest	63	63
	Grasslands/Herbaceous	458	382
	Logging	2	2
	Shrubland	75	51
Upper Governor Creek Total		600	498
Upper Rock Creek	Bare Rock/Sand/Clay	3	3
	Evergreen Forest	190	190
	Grasslands/Herbaceous	1373	1144
	Logging	21	21
	Pasture/Hay	11	7
	Shrubland	359	242
Upper Rock Creek Total		1955	1606

Table A-6. Existing and potential sediment loads from upland erosion by land cover type for each 6th code HUC (Sub-Watershed) and for the upper Big Hole watershed (i.e. all HUCs). The upper Big Hole watershed is bolded.

Subwatershed	**Land Cover Classification**	**Existing Sediment (tons/yr)**	**Potential Sediment (tons/yr)**
Upper Trail Creek	Deciduous Forest	1	1
	Evergreen Forest	247	247
	Fire	121	65
	Grasslands/Herbaceous	229	190
	Shrubland	201	135
	Logging	4	4
	Woody Wetlands	2	2
Upper Trail Creek Total		805	644
Upper Warm Springs Creek	Evergreen Forest	154	154
	Grasslands/Herbaceous	132	110
	Shrubland	100	67
Upper Warm Springs Creek Total		386	331
West Fork Ruby Creek	Evergreen Forest	269	269
	Grasslands/Herbaceous	169	140
	Shrubland	132	89
West Fork Ruby Creek Total		570	499
Upper Big Hole Watershed	**Bare Rock/Sand/Clay**	**56**	**56**
	Deciduous Forest	**2**	**2**
	Emergent Herbaceous Wetlands	**5**	**5**
	Evergreen Forest	**9315**	**9315**
	Fire	**851**	**450**
	Grasslands/Herbaceous	**21238**	**17691**
	Logging	**459**	**459**
	Pasture/Hay	**93**	**57**
	Shrubland	**11198**	**7546**
	Small Grains	**170**	**10**
	Woody Wetlands	**27**	**27**
Upper Big Hole Watershed Total		**43414**	**35618**

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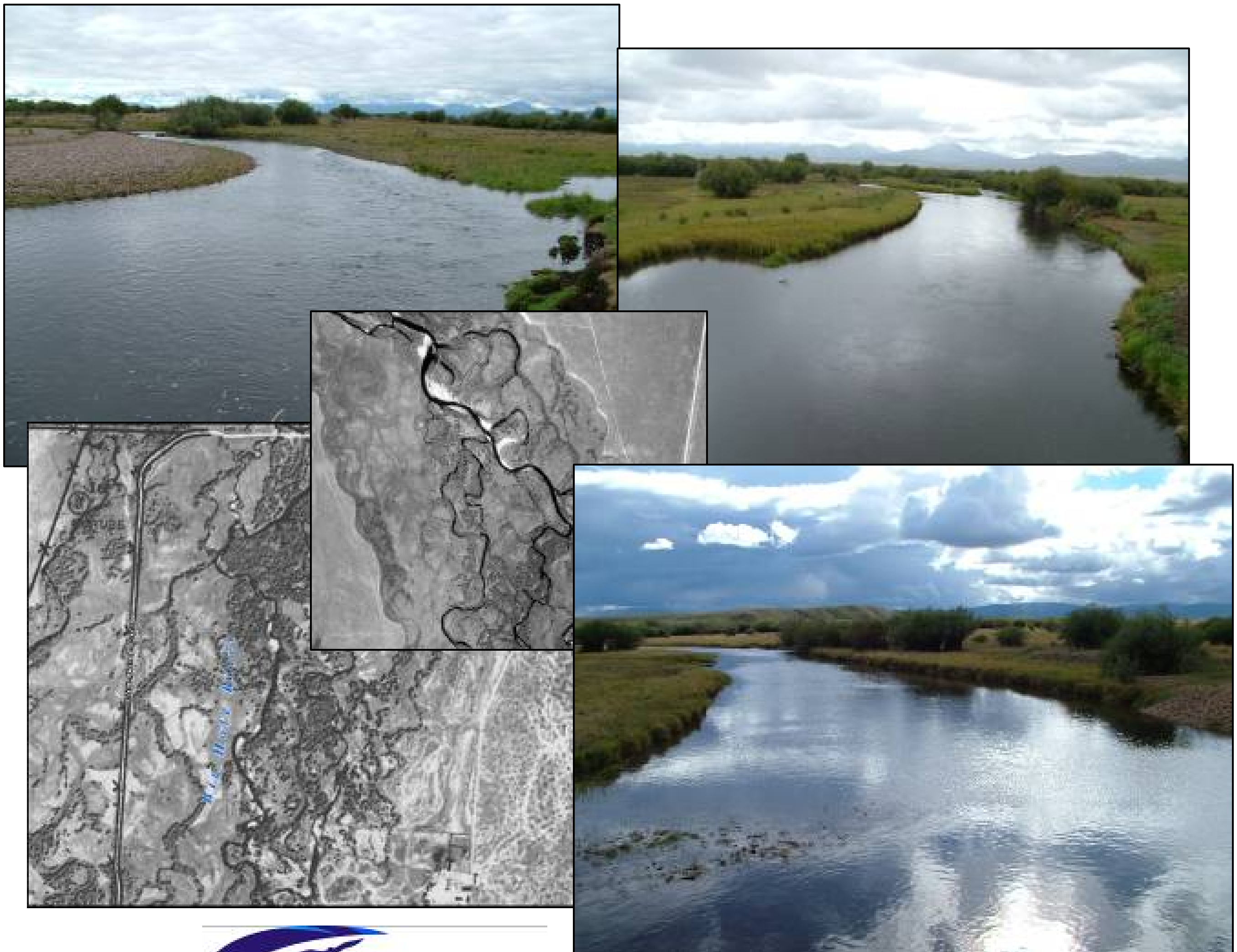
APPENDIX B
MODELING STREAM TEMPERATURES IN THE UPPER BIG HOLE RIVER - 2003



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Upper Big Hole River photos

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Outreach and landowner coordination: *Big Hole River Watershed Committee and Big Hole River Foundation*
Data Collection: *Confluence Consulting, United States Forest Service, Big Hole River Watershed Committee*

SECTION 1.0 BACKGROUND

Non-point source thermal loading presents a scenario that differs from most pollutants, in that the "sources" are not sources of heat in the true sense. Rather, alterations to riparian vegetation, channel geometry, and flow volumes influence insolation of the stream surface and decreased thermal inertia that alters temperatures. These alterations are pronounced along much of the Big Hole River. This investigation identifies how these factors influence temperatures along the upper Big Hole River above Pintlar Creek. This was completed via water temperature, stream flow, riparian vegetation, and stream channel measures and their use within a modeling framework called the Stream Segment Temperature Model (SSTEMP).

Initially, an aerial photo analysis, combined with field investigations, identified reaches where modifications to riparian vegetation and channel geometry possibly contributed to thermal loading. Also in the aerial assessment, reference areas were discovered and subsequently monitored to determine reasonable restoration conditions.

Other potential sources include irrigation return flows of three types. First are ditch returns where ditches re-intercept streams. Ditches in the Big Hole River probably vary in terms of their potential to accrue temperature; however, field observations in 2005 indicated many ditches had sparse shading and long residence times, factors that may promote warming (Confluence, unpublished data). Discrete, but intermittent, inputs of overland flow across fields present another potential source of thermal loading. Field observers noted several instances of overland flow entering streams at discernable locations. These were likely the result of years of flood irrigation waters cutting distinct channels through irrigated pastures. The third type of irrigation return flows were diffuse returns via overland flow. Presumably, groundwater return flows would be relatively cool, although residence time and associated factors make this difficult to predict. Given the unpredictable and potentially ephemeral locations of these features, determination of their influence on stream temperature was not possible during this project. These sources will be addressed through long-term monitoring and the adaptive management approach.

Riparian vegetation attributes, channel geometry, stream flow, and water temperature monitoring supported a thermal modeling approach to source assessment and provided the basis to allocate thermal pollution among influential factors in the Big Hole. The influential factors investigated to determine their role in attenuating thermal loading included riparian vegetation, channel geometry, and flow volume. Human caused shifts to these physical factors have resulted in elevated water temperatures in the Big Hole River that have commonly reached levels known to be harmful to fluvial Arctic grayling, the most sensitive fish species present.

Following review of a variety of options, the SSTEMP model emerged as the preferred method for allocating thermal pollution among the influential factors in the project area. SSTEMP had the most useful features and produced the most meaningful output given a relatively small budget for input data collection. In addition, this model addressed specific concerns in the upper Big Hole River planning area; specifically, the roles of channel widening, canopy removal, and irrigation withdrawals on thermal loading.

SECTION 2.0 MODEL CONSIDERATIONS

The Stream Segment Temperature Model or SSTEMP (Bartholow, 2002) applied to the Big Hole River conditions evaluates the thermal effects of proposed restoration strategies on individual stream segments. SSTEMP is a Windows based, simplified version of the Stream Network Temperature Model (SNTEMP) designed to develop temperature models for large stream systems or networks (Bartholow, 2002). SSTEMP is a physically based model that operates on basic energy balance principles. Data inputs include hydrology, meteorology, stream channel geometry, time of year, and shading (topographic and vegetative). SSTEMP includes a sensitivity and uncertainty analysis feature, which allows the modeler to see which input parameters have the greatest effect on the predicted output. The model gives predictions of mean daily and maximum water temperatures at the downstream end of the modeled reach.

SSTEMP evaluates the effects of proposed management strategies on temperature in individual stream segments, making it an excellent choice to allocate thermal pollution to the three influential factors in thermal data collection reaches. Nevertheless, limitations exist in any model. In the case of SSTEMP, several of the assumptions were inapplicable to the existing physical conditions in the upper Big Hole River planning area. Specifically, SSTEMP applies to single thread channels and the Big Hole River in this planning area is a naturally, highly braided system, which complicated both data collection and modeling efforts. Water management activities in the basin also confound attempts to model temperature. Irrigation activities increase the complexity of the system as irrigation ditches crossed multiple channels or mixed water by inter-basin transfers. In several instances, irrigation return flows reentering the Big Hole via overland flow were observable. Many small surface inputs are difficult to simulate with SSTEMP, which assumes that any gain in flow within a reach comes directly from groundwater. Because overland return flow sources are not visible on maps or aerial photos, it was difficult to account for these features in site selection.

Another challenge in applying the SSTEMP in valley portions of the upper Big Hole River planning area is its inherent bias in terms of model inputs designed for forested watersheds. The model computes shading of the stream based on a series of input parameters that describe the extent of vegetation along the stream corridor. The input parameters include vegetation height, offset, crown diameter, and density, parameters developed for trees with limited applicability to shrubs, which are the primary vegetative form providing streamside shading (**Figure B-1**). As a result, model inputs designed for trees with single trunks and a defined canopy, needed modification to apply to multi-stem shrubs lacking a defined canopy.

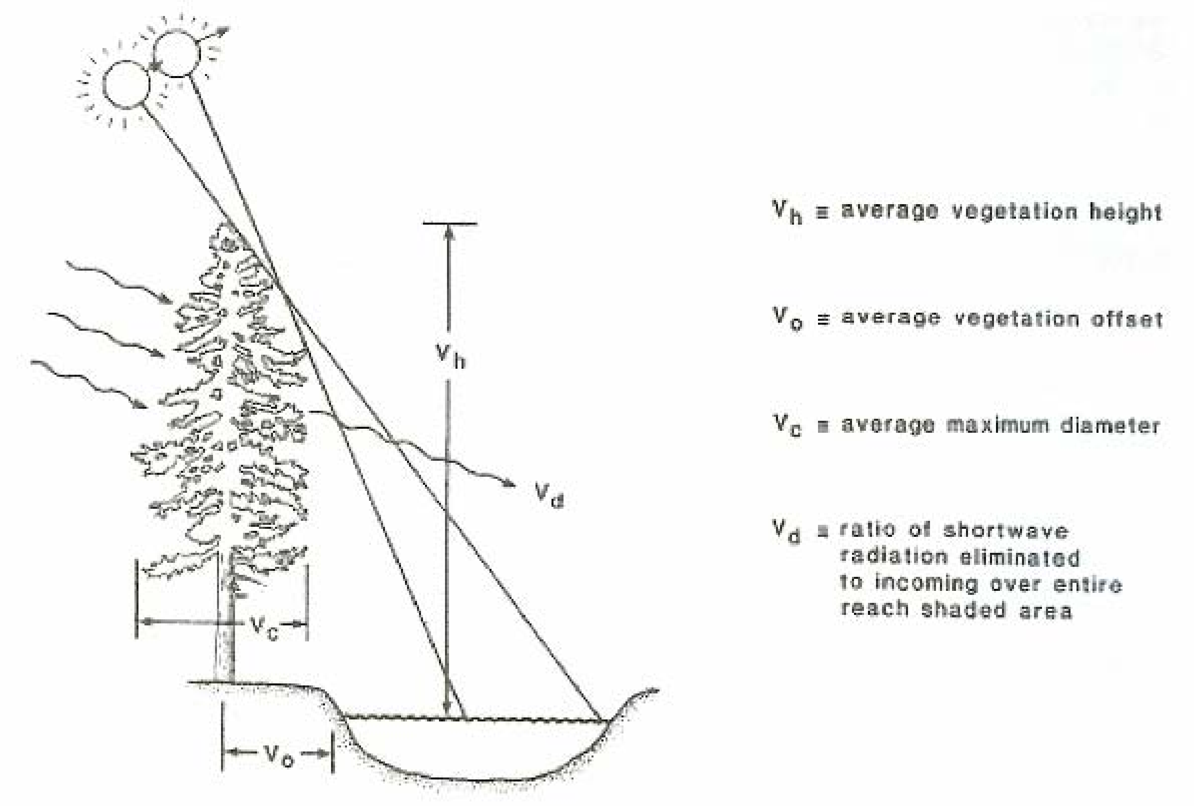

Figure B-1: SSTEMP vegetation shading variables (from Bartholow 2002).

Meteorological data from the National Oceanic and Atmospheric Administration's (NOAA) local climatological data reports was used for model input (Bartholow, 2002). These data are available for weather stations at Wisdom, MT and Jackson, MT in the Big Hole River valley, but only includes temperature and precipitation data and lacks other weather inputs such as wind speed, relative humidity, and solar radiation.

Preferably, application of the SSTEMP model results in development of a calibrated model to aid in the allocation of thermal loading among sources. Weather impeded these efforts with an unseasonable cold spell occurring during field efforts to collect key model inputs, including stream flow and temperature. As a result, data were not representative of conditions likely to result in elevated temperatures, limiting the ability to develop a calibrated model that described temperatures likely to exceed water quality standards. Therefore, the model was calibrated to these conditions and then hot summer weather conditions were applied to simulate the most sensitive timeframe when Montana's temperature standards are likely exceeded.

This assortment of limitations and confounding factors precluded the ability to produce a fully calibrated model for the upper Big Hole River planning area. The alternative was development of a demonstrative model using flow, temperature, and meteorological data available from the summer of 2004. This alternative was feasible given the relatively small data collection budget. Because it has not been fully calibrated, the drawback of a demonstrative model is that it cannot be used to predict actual, resultant temperatures over a wide range of hydrologic and meteorological conditions. Nevertheless, a demonstrative model, based on worst-case scenario conditions, provides a means to compare the *relative significance* of altered flow rate, riparian vegetation, and channel geometry on thermal loading and reach outflow temperatures.

SECTION 3.0 METHODS

Five reaches on the Big Hole River, and a single reach on Pintlar Creek, were the subjects of thermal modeling efforts (**Table B-1**). These reaches represented both least impacted or reference reaches, and impacted reaches, and all lie within the valley portions with a dominant shrub understory. Reference reaches provided the "potential" or least impacted channel dimensions and riparian shading characteristics for use in developing allocations. Thermal models were developed for four of the seven monitored reaches. BH09 and BH19 were excluded from modeling because extensive braiding confounded thermograph placement. Confounding monitoring and environmental factors precluded modeling PC04 at this time.

Table B-1: Reaches included in thermal monitoring efforts for the upper Big Hole River planning area.

Stream	*Reach*	*Reference or Impacted*
Big Hole River	BH09	Reference
Big Hole River	BH18	Reference
Big Hole River	BH19	Impacted
Big Hole River	BH22	Impacted
Big Hole River	BH26	Impacted
Big Hole River	BH28	Reference
Pintlar Creek	PC04	Impacted

Field data collection to support thermal modeling included stream flow measurement, temperature monitoring, and measures of riparian vegetation. Segment inflow and outflow were measured in the field using a Swoffer horizontal axis propeller flow meter. Estimation of average velocities followed the six-tenths depth method. None of the four reaches modeled had evidence of significant groundwater inflow or mid reach irrigation withdrawal at the time of sampling. Differences between reach inflow and outflow fell into the range that could be the result of the inherent error associated with flow measurement in open channels (+/-10 percent). Reaches were considered neither gaining nor losing flow in the demonstrative models.

Remote data loggers placed at the ends of each reach recorded inflow and outflow temperatures at 30-minute increments from July through September 2004. These data provided the input parameters for the demonstrative model that reflected field conditions. Accretion temperature, which is generally the same as groundwater temperature, was approximated by the mean annual air temperature recorded for Montana for the period of record from 1931 to 2000 (NOAA, 2002). This may differ in the upper Big Hole River planning area because the shallow groundwater, augmented by flood irrigation practices, may not be the standard temperature. Although at the time of monitoring these reaches appeared to not be gaining groundwater, but localized interactions between surface and groundwater may occur.

Modifications of prescribed field measures of riparian vegetation corrected the SSTEMP's bias towards forested, as opposed to shrub dominated riparian areas, the latter of which dominate the upper Big Hole River mainstem. These modifications account for differences in life form and canopy dimensions between trees and shrubs. As a single main trunk rarely exists in willow thickets, vegetation offset was the distance from the waters edge to the center of the first clump of willows. Measures of the vegetation crown provided information on the general width of the willows. Where willows were overhanging the waters edge the vegetation offset was set at 0 ft and the vegetation crown was given a value of two times the distance that vegetation was overhanging the waters edge. Median values for the shading parameters were applied to all reaches except BH26, for which the parameters that were measured at transect C were used because this transect better represented the whole reach than the median value when comparing to aerial photos of the reach.

Vegetation density was calculated by first determining the length of bank within a reach that was covered by either thick vegetation (healthy, mature willows), thin vegetation (unhealthy or sparse willows and tall grass), or non-shade producing vegetation (short grasses or bare ground). Analysis of the available aerial photos for each reach with ArcView 9.0 GIS/mapping software provided the basis for these classifications. Thick vegetation was assumed to filter approximately 85 percent of light, and thin vegetation was assumed to filter approximately 65 percent of light. All other areas were assumed to filter zero percent of light. A length-weighted average of vegetation density was determined and applied in the model. These estimates are based upon field measures and comparison to measured vegetation types with values provided by Bartholow in SSTEMP modeling guidance.

Mean reach latitude, reach length, upstream elevation, and downstream elevation were determined using GIS/mapping techniques in ArcView Version 9.0. Width's A term was determined by methods described by Bartholow (2002) assuming that the width's B term was a constant value of 0.2. Manning's n was estimated based on **Equation 1**, (Sturm, 2001) which relates Manning's n to the mean sediment diameter determined from pebble counts performed in the field.

Equation 1: $n = 0.04 d_{50}^{1/6}$ *d_{50} given in ft*

Results were validated by comparison with channel photos showing typical conditions and associated Manning's n values (Sturm, 2001).

The demonstrative SSTEMP models were developed based on meteorological conditions that could be expected on a hot summer day in the upper Big Hole River valley (**Table B-2**). Mean air temperature was selected based on the mean temperature for July in Montana and ground temperature was based on average annual air temperature for Montana (NOAA 2002). Because the upper Big Hole River planning area is cooler than most of Montana, this is probably an overestimate of average monthly temperatures, but represents some of the warmest days in July in this study area. A thermal gradient of 1.65 j/m²/s/C is the recommended default value (Bartholow, 2002). Selected sun and dust coefficient values represented a clear, cloudless day. Ground reflectivity followed values developed by the Tennessee Valley Authority (TVA) (Bartholow 2002) for a region made up mostly of meadows and fields. All of the reach models were run using the same meteorological input parameters.

Table B-2: Meteorological parameters used in the demonstrative SSTEMP models.

Input Parameters	Value
Mean Air Temperature	67.0 °F
Max Air Temperature	85.0 °F
Relative Humidity	15 %
Wind Speed	5.0 mph
Ground Temperature	42.4 °F
Thermal Gradient	1.65 j/m²/s/C
Possible Sun	100 %
Dust Coefficient	3.5
Ground Reflectivity	14.0 %

SSTEMP models of the four selected reaches were run with input parameters describing the existing conditions in each reach. Model outputs included predicted mean daily and maximum temperatures at the outlet of each reach. Initial results were compared with actual water temperature data from July 15, 2004 to determine the model's validity. Meteorological conditions and stream flow data from that date closely matched the inputs used in the demonstrative models. Model results matched measured stream temperatures closely, though the model generally predicted higher outflow temperature than were observed in the field (**Table B-3**).

Table B-3: Reach model validation.

Reach	**Predicted Mean Temperature (°F)**	**Measured Mean Temperature (°F)**	**Predicted Maximum Temperature (°F)**	**Measured Maximum Temperature (°F)**
BH18	66.32	64.49	77.95	73.75
BH22	67.56	66.47	80.30	73.44
BH26	66.97	66.75	79.89	76.44
BH28	66.27	N/A	78.10	N/A

Model validation included a sensitivity analysis, which allows identification of the most influential parameter on thermal regime. Results of the sensitivity analysis showed that model outputs were highly dependent on accuracy of data describing stream flow, air temperature, relative humidity, wind speed, and possible sun. Site specific stream flow data for July 15, 2004 were unavailable and had to be estimated based on USGS stream gage data from Wisdom, MT. The lack of highly accurate, site-specific meteorological and stream flow data was likely the cause of the discrepancies between model outputs and actual temperatures measured in the field. Temperature data were unavailable for the downstream end of reach BH28 for the dates modeled (data loggers could not be located during retrieval), but the results from the other three reaches show that models give acceptable results given the level of uncertainty in the input data.

A paired reach approach allowed evaluation of the relative influence of riparian vegetation and channel geometry on stream temperature. Following the initial model runs evaluating existing conditions on the four reaches, four additional alternatives for each of the impaired reaches (BH22 and BH26) allowed estimation of the relative importance of riparian vegetation, channel geometry, and stream flow on temperature (**Table B-4**). In additional scenario runs, input parameters allowed demonstration of the relative effect of restoring riparian vegetation, channel geometry, or both riparian vegetation and channel geometry to reference conditions on water temperature. Because SSTEMP cannot compute cumulative effects of changing a single physical characteristic of the stream system (Bartholow 2002), reduced vegetation and altered channel geometry were changed simultaneously to reference conditions in an attempt to estimate the possible cumulative effect of a more complete stream restoration. BH18 was the reference for vegetation characteristics for both BH22 and BH26, as its riparian community represented "least impaired" with implementation of reasonable soil and water conservation practices. BH18 was also the reference for channel geometry for BH22. In contrast, BH28 was the channel geometry reference reach for BH26 to more closely approximate channel geometry changes that occur naturally moving downstream along the river continuum.

Table B-4: Modeled scenarios for reaches BH22 and BH26 to evaluate the relative importance of riparian vegetation, channel geometry, and stream flow on temperature.

Number	Modeled Scenarios
1	Existing vegetation and channel geometry over a range of flow rates;
2	Existing channel geometry with vegetation changed to reference conditions over a range of low rates;
3	Existing vegetation with channel geometry changed to reference conditions over a range of low rates; and
4	Vegetation and channel geometry changed to reference conditions over a range of low rates.

No records of stream flow exist for the Big Hole River prior to the inception of agricultural development and irrigation practices that affect minimum flows in the basin (Confluence et al. 2003). As a result, quantification of potential low flow conditions for the Big Hole is unfeasible. Instead of selecting a specific value for minimum flow reference conditions, reaches were modeled over a range of flows. Outflow temperatures (daily mean and daily maximum) were predicted at increments of 10 cfs from 10 cfs to 100 cfs for all riparian vegetation and channel geometry conditions (reference and impaired).

SECTION 4.0
RESULTS & DISCUSSION

Application of the SSTEMP model to the upper Big Hole River indicates substantial decreases in both maximum and mean daily temperatures are possible with increased flow, narrower channels, and increased riparian shading. Nevertheless, an important consideration in interpreting these results is that the models developed for this study are demonstrative rather than predictive and have not been calibrated over a wide range of meteorological and hydrologic conditions. Modeled outflow temperatures were slightly higher than actual temperatures in most cases due to lack of high quality, site-specific meteorological input data. As the model has not been fully calibrated, using the model to predict actual outflow temperatures is inappropriate. However, comparison of the results is an appropriate and effective way to determine relative importance of riparian vegetation, channel geometry, and stream flow on water temperatures in the upper Big Hole and can be used for TMDL allocation.

Reach BH18 provided a reference for least impaired riparian vegetation and channel geometry. Because it was a riparian and channel condition reference reach, only existing conditions were modeled over a range of flow rates. Model results show that increasing flow has a minimal effect on mean daily outflow temperatures when vegetation and channel geometry are in a least impaired condition (**Figure B-2**). On the other hand, increasing stream flows has a significant inverse relationship with maximum daily outflow temperatures (**Figure B-3**). The greater the stream flow, the lower the predicted maximum temperature.

BH28 was also a reference reach, but only for channel geometry as the vegetation in BH28 was reduced considerably compared to BH18. Model results again show that increasing flow rate has minimal effect on lowering mean outflow temperatures but a significant effect on lowering maximum outflow temperatures (**Figures B-4 and B-5**). Model runs simulating improved vegetation predict decreases in both mean and max outflow temperatures.

Generally, the results show that improving vegetation and channel geometry and increasing flow rate results in lower mean and maximum outflow temperatures (**Figures B-6 through B-9**). The most marked decreases in predicted outflow temperatures occur when all the influential factors (vegetation, channel geometry, and flow) approximated reference conditions. In addition to these findings, closer analysis of the results provided a platform on which to base relative ranking of the three impairment categories based on their ability to attenuate thermal loading.

The relative roles of riparian vegetation and channel geometry differed in terms of influence on mean versus maximum daily temperatures. Changing riparian vegetation from impaired to reference conditions resulted in lower *mean* outflow temperatures when compared to the results of changing channel geometry from impaired to reference conditions (**Figures B-6 and B-8**). This was true for all modeled flow rates. Conversely, at all but the lowest flow rates, ($Q \leq 20$ cfs for BH22, and $Q \leq 10$ cfs for BH26), changing channel geometry from impaired to reference conditions resulted in lower *maximum* outflow temperatures when compared to the results of changing riparian vegetation from impaired to reference conditions (**Figures B-7 and B-9**). These results suggest that riparian vegetation has more effect on mean daily temperature than channel geometry, and that channel geometry has more effect on maximum daily temperature than riparian vegetation.

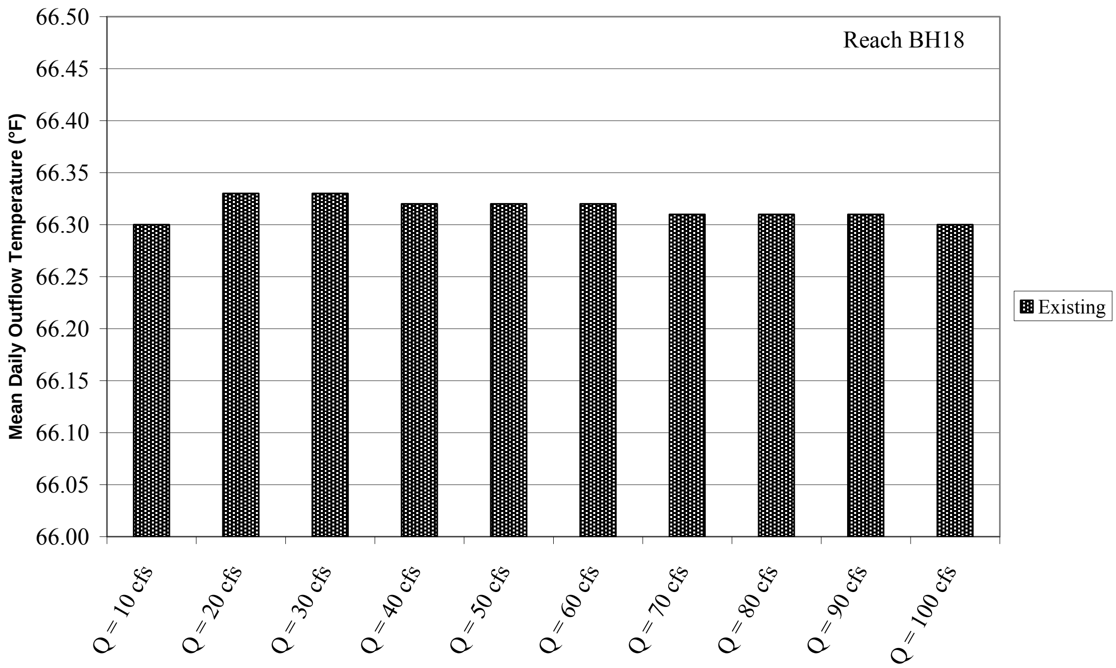

Figure B-2: Thermal modeling results*. Predicted mean daily outflow temperatures for reach BH18.

* Note on figures B-3 through B-9:

Existing - denotes a model run with input data describing existing riparian vegetation and channel geometry conditions

Veg. - denotes a model run with input data describing riparian vegetation in a least impaired (reference) condition

Geom. - denotes a model run with input data describing channel geometry in a least impaired (reference) condition

Both - denotes a model run with input data describing channel geometry and vegetation in a least impaired (reference) condition

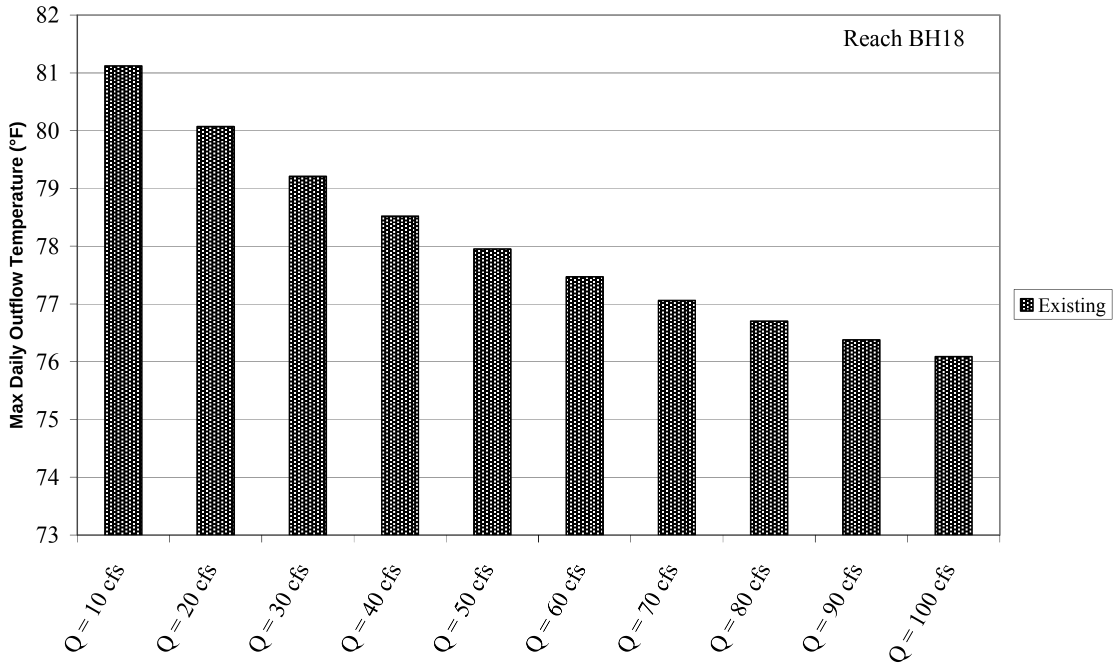

Figure B-3: Thermal modeling results*. Predicted max daily outflow temperatures for reach BH18.

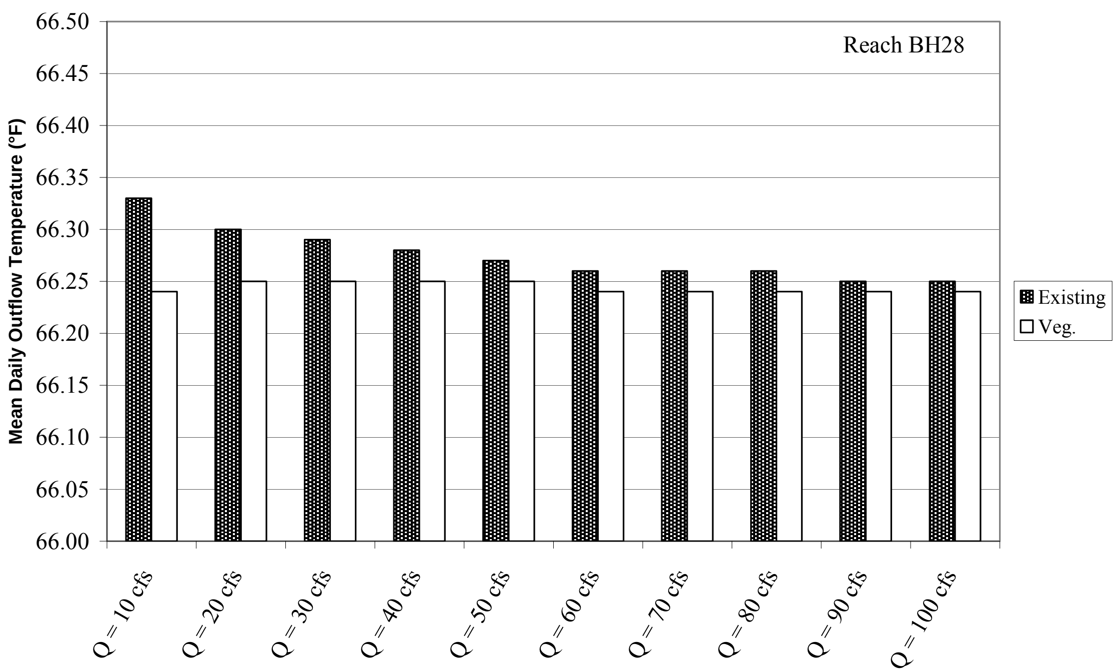

Figure B-4: Thermal modeling results*. Predicted mean daily outflow temperatures for reach BH28.

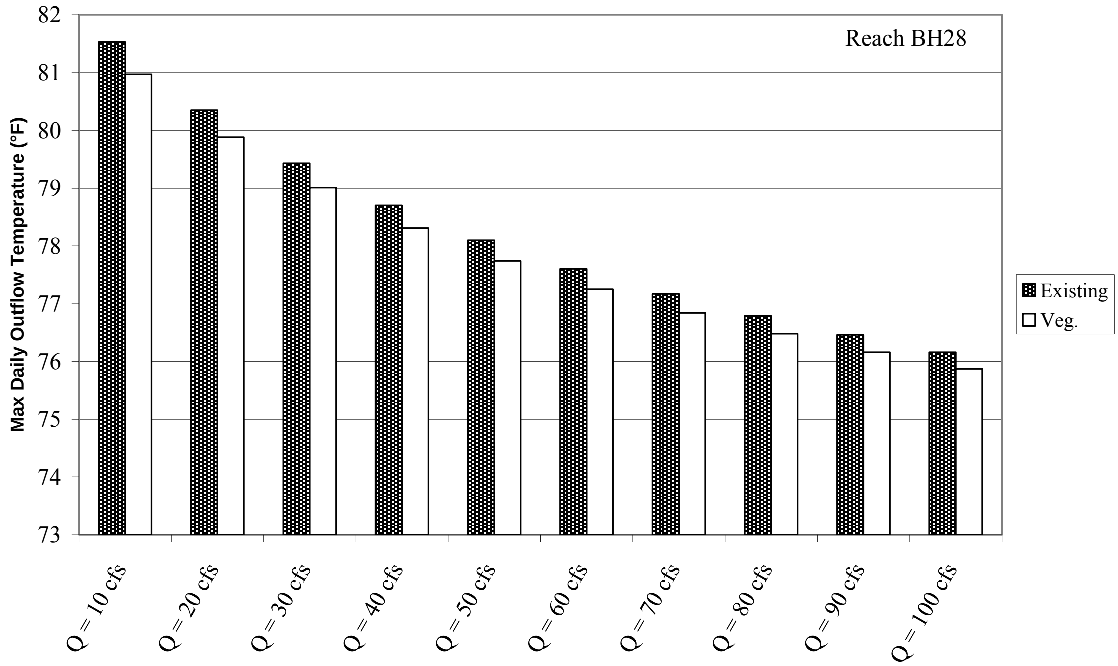

Figure B-5: Thermal modeling results*. Predicted max daily outflow temperatures for reach BH28.

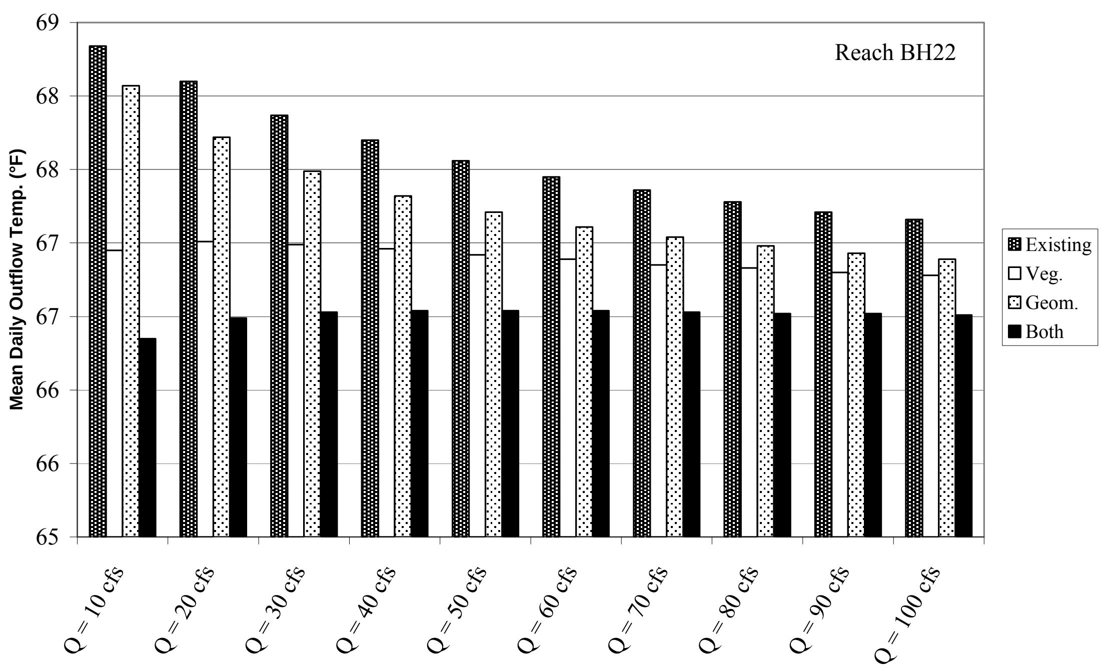

Figure B-6: Thermal modeling results*. Predicted mean daily outflow temperatures for reach BH22.

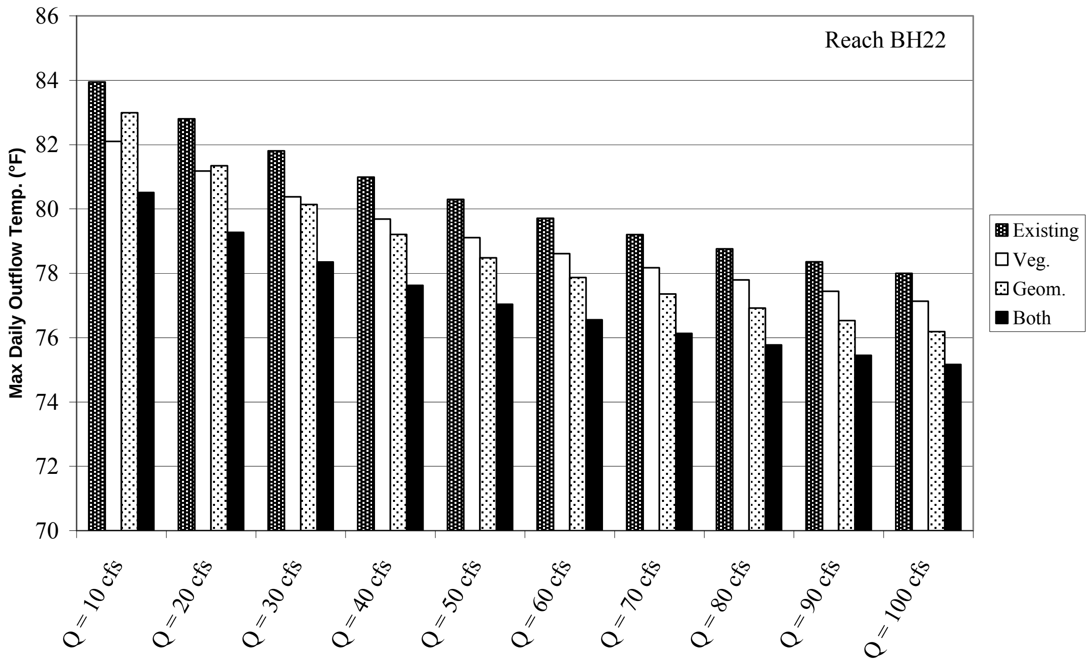

Figure B-7: Thermal modeling results*. Predicted max daily outflow temperatures for reach BH22.

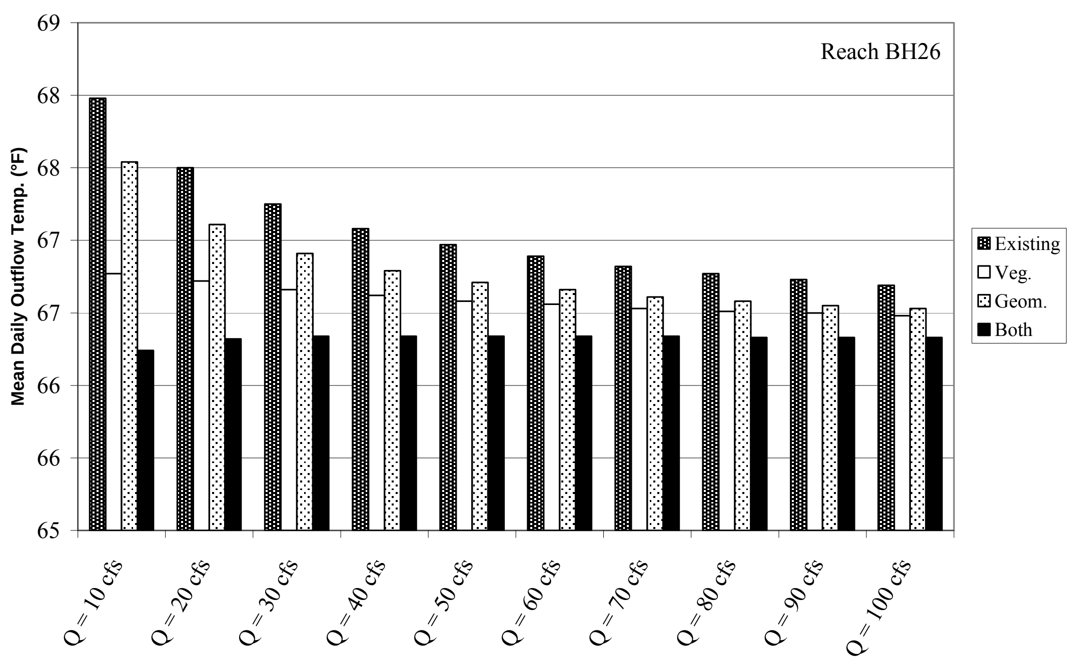

Figure B-8: Thermal modeling results*. Predicted mean daily outflow temperatures for reach BH26.

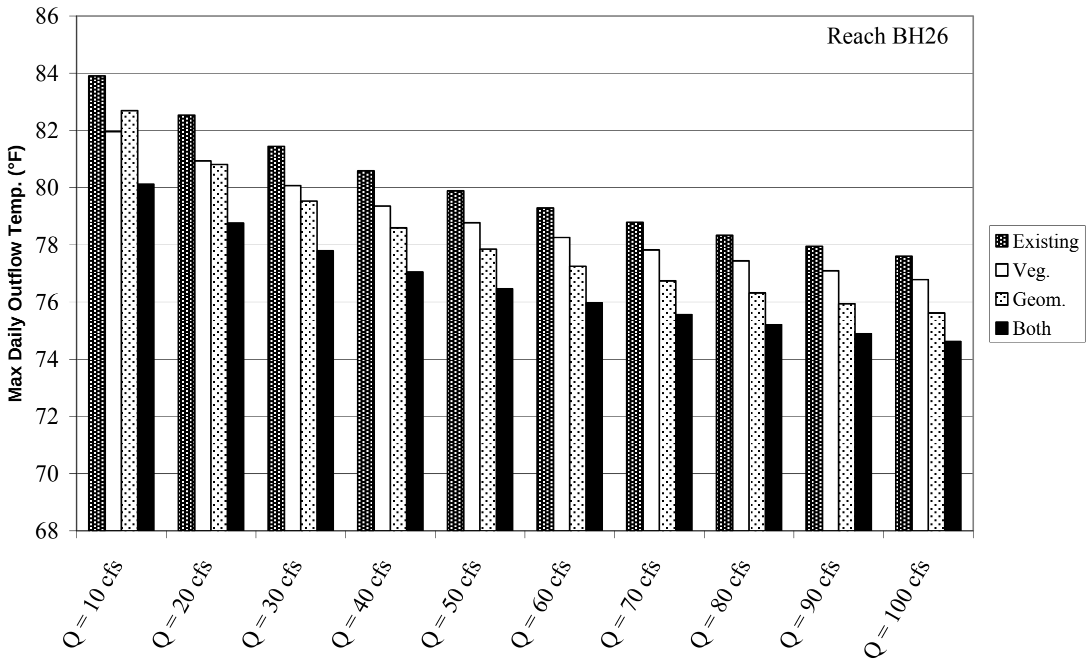

Figure B-9: Thermal modeling results*. Predicted max daily outflow temperatures for reach BH26.

These seemingly confounding results can be explained when the interaction between the components of the stream system are considered from a heat transfer perspective. When vegetative shading approaches reference conditions, a shift in the diel (24-hour) temperature regime occurs. Increased shade from the additional vegetation keeps sun off the water, which decreases maximum daily temperatures to some extent. At the same time, channel width remains in the impaired, overly wide state resulting in the maximum amount of cooling from the large exposed water surface during the night and in turn low minimum temperatures. Lower maximum daily temperatures combined with lower minimum daily temperatures result is a significant decrease in mean daily temperatures. When channel geometry mimics reference conditions, a buffering effect on temperatures occurs. Because less water surface is available as a heat transfer interface (heating by day and cooling by night), the result is lower maximum daily temperatures and higher minimum daily temperatures. The mean temperature changes little, while daily maximum temperatures decrease by a large amount. Of course, changing both riparian vegetation and channel geometry to reference conditions combines the effects described above; resulting in significantly lower mean and maximum daily reach outflow temperatures. These results emphasize the need to consider both maximum daily and mean daily temperatures in establishing thermal targets for the Big Hole River.

Modeling predicts that maximum outflow temperatures decrease significantly with increased flow rates for all modeled reaches, as larger volumes of water require a greater thermal energy input to experience equal gains in temperature. In addition, travel time (the time required for a piece of water to travel the length of a reach) generally decreases with increased flow because flow velocities increase. Water spends less time in a given reach and has less time to collect thermal pollution. Modeling results for reaches BH22 and BH26 suggest that mean outflow temperatures also decrease with increased flow rates when the model inputs describe existing impaired conditions, riparian vegetation returned to a least impaired state, or channel geometry returned to a least impaired state. When both riparian vegetation and channel geometry are modeled in a least impaired state, or when reference reaches are modeled in their existing state, increased flow rate has a minimal affect on mean daily temperatures. In fact, at lower flow rates (10 – 40 cfs) model results suggest that mean daily outflow temperatures actually increase very slightly (less than ½ of one °F) as flow rate increases. As flow rate increases above 40 cfs the predicted mean daily outflow temperatures begin to decrease slightly again.

Again, the interactions between components of the stream system from a heat transfer perspective explain the failure of increases in flow to have significant effect on mean daily temperatures. As flow rate increases from 10 cfs to 40 cfs, the open water surface area increases resulting in greater cooling effect at night. During the day, dense vegetation that lines the channel shades only a portion of the heating surface so more heat is lost at night than is gained during the day. The result is a lower minimum daily temperature and a near constant maximum daily temperature. The nighttime heat loss is the dominant factor in this case. As flow rates increase above 40 cfs, travel time decreases enough to become the dominant factor and cause large enough decreases in maximum temperature that the mean temperature begins to decrease again. Reaches BH22 and BH26 were 6 and 2.6 miles long respectively indicating BH22 has greater potential to lose heat at night compared to BH26.

Modeled flows include proposed targets for Arctic grayling conservation and other flows used in conservation planning. The CCAA plan for the Big Hole River calls for variable minimum flows in this portion of the Big Hole River depending on season and reach designation (MFWP in press). The prescribed minimum flow for reaches BH22 and BH26 are 60 and 100 cfs, respectively during summer months. A minimum survival flow of 20 cfs has been used as a trigger in the Big Hole River drought management plan and is used here to evaluate the sufficiency of these flows in maintaining a thermal regime favorable to Arctic grayling.

A break down of the modeling results shows the relative effects of improving flow volume, riparian vegetation, and channel geometry on mean daily temperatures (**Table B-5**) which provides the basis for allocating thermal loading among the three primary sources. Examining the change in predicted mean daily outflow temperatures when impacts are changed from impacted to reference conditions suggests that riparian vegetation is the most significant single factor influencing temperature. Stream flow rate and channel geometry follow in order of decreasing significance. In contrast, when considering maximum daily temperatures, stream flow rate was the most significant factor influencing water temperatures (**Table B-6**). Channel geometry and riparian vegetation follow in order of decreasing significance.

Table B-5: Predicted mean daily outflow temperature deviation from predicted temperatures for existing, impaired conditions.

Reach ➔		***BH22***			***BH26***		
Code * ➔		***Existing***	***Veg.***	***Geom.***	***Existing***	***Veg.***	***Geom.***
Predicted Daily Mean Outflow Temperature, T (°F)	Q = 20 cfs	0.00	-1.09	-0.38	0.00	-0.78	-0.39
	Q = 30 cfs	-0.23	-0.88	-0.38	-0.25	-0.59	-0.34
	Q = 40 cfs	-0.40	-0.74	-0.38	-0.42	-0.46	-0.29
	Q = 50 cfs	-0.54	-0.64	-0.35	-0.53	-0.39	-0.26
	Q = 60 cfs	-0.65	-0.56	-0.34	-0.61	-0.33	-0.23
	Q = 100 cfs	-0.94	-0.38	-0.27	-0.81	-0.21	-0.16
	-0.55	-0.72	-0.35	-0.52	-0.46	-0.28	-0.30

* Existing - denotes a model run with input data describing existing riparian vegetation and channel geometry conditions
Veg. - denotes a model run with input data describing riparian vegetation in a least impaired (reference) condition
Geom. - denotes a model run with input data describing channel geometry in a least impaired (reference) condition

Table B-6: Predicted maximum daily outflow temperature deviation from predicted temperatures for existing, impaired conditions.

Reach ➔		***BH22***			***BH26***		
Code * ➔		***Existing***	***Veg.***	***Geom.***	***Existing***	***Veg.***	***Geom.***
Predicted Daily Maximum Outflow Temperature, T (°F)	Q = 20 cfs	0.00	-1.62	-1.46	0.00	-1.60	-1.73
	Q = 30 cfs	-0.99	-1.43	-1.67	-1.09	-1.38	-1.92
	Q = 40 cfs	-1.81	-1.30	-1.78	-1.95	-1.23	-2.00
	Q = 50 cfs	-2.50	-1.19	-1.82	-2.65	-1.12	-2.04
	Q = 60 cfs	-3.09	-1.10	-1.84	-3.25	-1.03	-2.04
	Q = 100 cfs	-4.80	-0.87	-1.81	-4.94	-0.81	-1.99
	Average	-2.64	-1.25	-1.73	-2.78	-1.20	-1.95

* Existing - denotes a model run with input data describing existing riparian vegetation and channel geometry conditions
Veg. - denotes a model run with input data describing riparian vegetation in a least impaired (reference) condition
Geom. - denotes a model run with input data describing channel geometry in a least impaired (reference) condition

Modeling results indicate thermal regime in the upper Big Hole River relates to the three major influential factors, riparian shading, stream flow, and channel geometry, in different ways. Based on analysis of mean daily outflow results of the SSTEMP models, the most significant factor influencing thermal pollution to the upper Big Hole is impaired riparian vegetation, followed by impaired stream flow, and channel geometry (in decreasing order of significance). Based on analysis of maximum daily outflow results of the SSTEMP models, the most significant source of thermal pollution to the upper Big Hole River is reduced stream flow, followed closely by impaired riparian vegetation and channel geometry. The modeling effort identifies that the state water quality temperature standards are likely exceeded and that all three factors significantly affect instream water temperatures.

Although not included in this modeling and allocation effort, it is likely that overland irrigation return flows and ditch returns are potential sources of thermal pollution and may have significant effects on temperatures in the upper Big Hole River (**Figure B-10**). During the TMDL development effort, the impact from this source is not well known. Recent fish-sampling efforts in some ditches were frequently ceased by early afternoon because temperatures exceeded MFWP's guidelines of 59 °F (Confluence, unpublished data). Efforts have been initiated through fisheries restoration efforts that will identify ditches that are contributing to the thermal loading. Relatively long residence time combined with low shrub cover likely contribute to warming in ditches. Similarly, overland flow entering streams at discrete locations presents another potential source of warm water (**Figure B-11**). Due to their unpredictable locations and ephemeral nature, estimation of their influence on temperature is unfeasible with the available resources. A color infrared imaging (CIR) flight calibrated to stream temperature was completed during the summer of 2008 via fishery restoration efforts but results are not available at this time. The results of the CIR imaging will be useful to identify warm water irrigation impacts.

Figure B-10: Example of a larger irrigation ditch in the upper Big Hole River planning area.

In conclusion, modeling thermal inputs and temperature regime in the Big Hole River is challenging given a variety of factors. Extensive channel braiding, a complicated irrigation infrastructure with approximately 1000 diversions in the basin, and unidentified inputs from ditch returns and discrete surface returns, all thwart attempts to identify magnitudes and relative contributions among sources during this modeling effort. Application of the SNTEMP model, which examines a stream network, is Unfeasible in the upper Big Hole River planning area. This approach would require potentially hundreds of thermographs and flow measurements to capture the influence of irrigation withdrawals and returns and the extensive braiding. Nevertheless, these SSTEMP model results provide information to prioritize among actions to meet water quality standards both over the long and short-term and also provide a basis for initial allocations. An adaptive management approach will be identified in the TMDL to further the understanding about irrigation water return flow impacts.

Figure B-11: Example of a discrete source of overland return of irrigation water to the Big Hole River.

SECTION 5.0 CONSIDERATIONS FOR BUILDING ALLOCATIONS FOR SOURCES OF THERMAL LOADING

Results of the SSTEMP modeling (0 Results and Discussion) provide the technical basis to allocate temperature loading among the influential factors (flow volume, channel geometry, and riparian shading.) As discussed, calculation of estimated load allocations or an explicit loading margin of safety is not useful for restoration efforts. Therefore, development of surrogate allocations following EPA guidance (EPA 1999) is appropriate in the main TMDL document.

Probable sources of impairment are another consideration in development of allocations. Agricultural activities, including cattle grazing, hay production, and willow removal, are the human influences responsible for alterations of three factors across the basin. Other human influences, such as transportation corridors, presumably have a negligible influence on thermal loading, and therefore have no performance-based allocation.

A brief review of the links among human activities, the measured perturbations, and water quality supports these allocations. The links between flow withdrawals, flow volumes, and water temperature are straightforward. Modeling results indicate that instream flows are a significant influence on water temperatures (**Table B-7**). Nevertheless, difficulties arise in determining the feasibility of achieving flow targets and the associated allocations given the complexity of the irrigation system and associated diversions and ditch networks above Wisdom. Recent efforts to identify and map diversions and ditches will assist in this effort. However, in the interim, it is not possible to determine the amount of irrigation water savings that can be realized from irrigation water management practices such as ditch lining, field leveling, installing gated pipes, or installing other practical water saving BMPs. Such an effort should have a high priority for future funding because it will be useful for prioritizing locations of the irrigation water management restoration activities.

The links among human activities to channel morphology, riparian shading, and temperature are also clear. Livestock grazing and mechanical removal of willows has reduced shading and bank resilience to high flows. These denuded banks are more susceptible to sheer stress resulting in lateral migration and the overly wide channel geomorphology. Combined, these factors have an adverse effect on water temperature, an assumption supported by data and thermal modeling.

A final consideration in adoption of this temperature allocation strategy is consideration of Montana's water law, which prohibits the taking or imperilment of any existing water right in order to attain water quality standards. Therefore, locally coordinated approach to restoring instream flow is essential for achieving the goal of the performance based allocation process that relates to instream flows. Local watershed groups, MFWP, and landowners, are currently working together to increase instream flow during drought and in CCAA efforts.

5.1 Margin of Safety and Seasonal Considerations

Margin of safety considerations for the thermal modeling assessment involve an implicit approach based on conservative assumptions. Modeling incorporated temperatures typical of Montana as a whole, which tends to be warmer overall than the upper Big Hole River planning area. Allocations to riparian shading incorporate data from a least impaired reach on the Big Hole River that had exemplary riparian conditions in conjunction with well-managed livestock grazing. Similarly, desired channel geometry follows a conservative approach based on three reference reaches showing stable channel geomorphology and width-to-depth ratios considerably lower than impaired reaches. A margin of safety is provided in assessing not only the factors that affect thermal loads, but also addressing instream flows that affect the streams capacity to adsorb heat without increasing temperature.

Seasonal considerations are considerable for temperature. Obviously, with high temperatures being a primary limiting factor for Arctic grayling in the Big Hole River, summer temperatures are a paramount concern. Therefore, focusing on summer thermal regime is the appropriate approach. Nevertheless, the types of perturbations in the upper Big Hole River planning area may also limit overwintering habitat. Removal of canopy cover increases formation of anchor ice, which may physically limit habitat for fish (Winegar 1977). This may be especially pronounced in overly wide sections where conditions for anchor ice formation are favorable. Therefore, although the allocations and restoration plans were developed chiefly with summer temperatures in mind, the aquatic community will also benefit during winter months because restoration scenarios used in the modeling will moderate cold ice forming conditions during the winter also.

SECTION 6.0 REFERENCES

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Attachment B-1. Modeling Stream Temperatures in the Upper Big Hole River

Info		Date	Geometry						
Model Reach	**Model Description**	**Month/ day**	**Latitude**	**Segment Length**	**Upstream Elevation**	**Downstream Elevation**	**Width's A Term**	**Width's B Term**	**Manning's n**
(--)	**(--)**		**(degrees)**	**(mi)**	**(ft)**	**(ft)**	**(s/ft2)**	**(--)**	**(--)**
BH18	existing conditions modeled	15-Jul	45.399	1.305	6400.89	6361.52	17.603	0.2	0.045
BH22	existing conditions modeled	15-Jul	45.502	6.089	6259.82	6171.24	26.561	0.2	0.041
BH22	vegetation changed to reference conditions	15-Jul	45.502	6.089	6259.82	6171.24	26.561	0.2	0.041
BH22	channel geometry changed to reference conditions	15-Jul	45.502	6.089	6259.82	6171.24	17.45	0.2	0.041
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	45.502	6.089	6259.82	6171.24	17.45	0.2	0.041
BH26	existing conditions modeled	15-Jul	45.639	2.61	6040	6003.91	27.049	0.2	0.042
BH26	vegetation changed to reference conditions	15-Jul	45.639	2.61	6040	6003.91	27.049	0.2	0.042
BH26	channel geometry changed to reference conditions	15-Jul	45.639	2.61	6040	6003.91	16.56	0.2	0.042
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	45.639	2.61	6040	6003.91	16.56	0.2	0.042
BH28	existing conditions modeled	15-Jul	45.662	0.534	5974.39	5961.26	17.625	0.2	0.039
BH28	vegetation changed to reference conditions	15-Jul	45.662	0.534	5974.39	5961.26	17.625	0.2	0.039

Attachment B-1. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Hydrology**			
Model Reach	**Model Description**	**month / day**	**Segment Inflow**	**Inflow Temp.**	**Segment Outflow**	**Accretion Temp.**
(--)	**(--)**	**(--)**	**(cfs)**	**(*F)**	**(cfs)**	**(*F)**
BH18	existing conditions modeled	15-Jul	20	66.2	20	42.4
BH22	existing conditions modeled	15-Jul	20	66.2	20	42.4
BH22	vegetation changed to reference conditions	15-Jul	20	66.2	20	42.4
BH22	channel geometry changed to reference conditions	15-Jul	20	66.2	20	42.4
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	20	66.2	20	42.4
BH26	existing conditions modeled	15-Jul	20	66.2	20	42.4
BH26	vegetation changed to reference conditions	15-Jul	20	66.2	20	42.4
BH26	channel geometry changed to reference conditions	15-Jul	20	66.2	20	42.4
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	20	66.2	20	42.4
BH28	existing conditions modeled	15-Jul	20	66.2	20	42.4
BH28	vegetation changed to reference conditions	15-Jul	20	66.2	20	42.4

Attachment B-1. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		Date	Meteorology								
Model Reach	**Model Description**	**Month / Day**	**Air Temp.**	**Max. Air Temp**	**Relative Humidity**	**Wind Speed**	**Ground Temp**	**Thermal Gradient**	**Possible Sun**	**Dust Coeff.**	**Ground Reflectivity**
(--)	**(--)**	**(…)**	**(*F)**	**(*F)**	**(%)**	**(mph)**	**(*F)**	**(j/m2/s/C)**	**(%)**	**(--)**	**(%)**
BH18	existing conditions modeled	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14
BH22	existing conditions modeled	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14
BH22	vegetation changed to reference conditions	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14
BH22	channel geometry changed to reference conditions	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14
BH26	existing conditions modeled	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14
BH26	vegetation changed to reference	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14

Attachment B-1. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		Date	Meteorology								
Model Reach	**Model Description**	**Month / Day**	**Air Temp.**	**Max. Air Temp**	**Relative Humidity**	**Wind Speed**	**Ground Temp**	**Thermal Gradient**	**Possible Sun**	**Dust Coeff.**	**Ground Reflectivity**
(--)	**(--)**	**(…)**	**(*F)**	**(*F)**	**(%)**	**(mph)**	**(*F)**	**(j/m2/s/C)**	**(%)**	**(--)**	**(%)**
	conditions										
BH26	channel geometry changed to reference conditions	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14
BH28	existing conditions modeled	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14
BH28	vegetation changed to reference conditions	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14

Attachment B-1. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Optional Shading Variables**										
Model Reach	**Model Description**	**Month/ Day**	**Segment Azimuth**	**Topo. Altitude (E)**	**Vegetation Height (E)**	**Vegetation Crown (E)**	**Vegetation Offset (E)**	**Vegetation Density (E)**	**Topo. Altitude (W)**	**Vegetation Height (W)**	**Vegetation Crown (W)**	**Vegetation Offset (W)**	**Vegetation Density (W)**
(--)	**(--)**	**(--)**	**(degrees)**	**(degrees)**	**(ft)**	**(ft)**	**(ft)**	**(%)**	**(degrees)**	**(ft)**	**(ft)**	**(ft)**	**(%)**
BH18	existing conditions modeled	15-Jul	-6.6	3	12	6	8	46.22%	3	13	6	12	73.12%
BH22	existing conditions modeled	15-Jul	-0.8	3	9	4	10	26.99%	3	4	2	1	4.39%
BH22	vegetation changed to reference conditions	15-Jul	-0.8	3	12	6	8	46.22%	3	13	6	12	73.12%
BH22	channel geometry changed to reference conditions	15-Jul	-0.8	3	9	4	10	26.99%	3	4	2	1	4.39%
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	-0.8	3	12	6	8	46.22%	3	13	6	12	73.12%
BH26	existing conditions modeled	15-Jul	5.2	1.5	6	2	20	7.80%	4	3	2	1	6.33%

Attachment B-1. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		Date	Optional Shading Variables										
Model Reach	**Model Description**	**Month/ Day**	**Segment Azimuth**	**Topo. Altitude (E)**	**Vegetation Height (E)**	**Vegetation Crown (E)**	**Vegetation Offset (E)**	**Vegetation Density (E)**	**Topo. Altitude (W)**	**Vegetation Height (W)**	**Vegetation Crown (W)**	**Vegetation Offset (W)**	**Vegetation Density (W)**
(--)	**(--)**	**(--)**	**(degrees)**	**(degrees)**	**(ft)**	**(ft)**	**(ft)**	**(%)**	**(degrees)**	**(ft)**	**(ft)**	**(ft)**	**(%)**
BH26	vegetation changed to reference conditions	15-Jul	5.2	1.5	12	6	8	46.22%	4	13	6	12	73.12 %
BH26	channel geometry changed to reference conditions	15-Jul	5.2	1.5	6	2	20	7.80%	4	3	2	1	6.33%
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	5.2	1.5	12	6	8	46.22%	4	13	6	12	73.12 %
BH28	existing conditions modeled	15-Jul	11.6	2	2.5	1	0	45.10%	5	8	2	2	60.85 %
BH28	vegetation changed to reference conditions	15-Jul	11.6	2	12	6	8	46.22%	5	13	6	12	73.12 %

Attachment B-1. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Model Results - Outflow Temperature**					
Model Reach	**Model Description**	**Month/ Day**	**Predicted Mean**	**Mean TOut - Mean TIn**	**Length Normalized Mean TOut - Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**	**(*F)**	**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 10 cfs					
BH18	existing conditions modeled	15-Jul	66.30	0.10	0.08	81.12	14.82	11.36
BH22	existing conditions modeled	15-Jul	68.34	2.14	0.35	83.95	15.61	2.56
BH22	vegetation changed to reference conditions	15-Jul	66.95	0.75	0.12	82.10	15.15	2.49
BH22	channel geometry changed to reference conditions	15-Jul	68.07	1.87	0.31	82.99	14.92	2.45
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	66.35	0.15	0.02	80.51	14.16	2.33
BH26	existing conditions modeled	15-Jul	67.98	1.78	0.68	83.91	15.93	6.10
BH26	vegetation changed to reference conditions	15-Jul	66.77	0.57	0.22	81.96	15.19	5.82
BH26	channel geometry changed to reference conditions	15-Jul	67.54	1.34	0.51	82.69	15.15	5.80
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	66.24	0.04	0.02	80.12	13.88	5.32
BH28	existing conditions modeled	15-Jul	66.33	0.13	0.24	81.53	15.20	28.46
BH28	vegetation changed to reference conditions	15-Jul	66.24	0.04	0.07	80.97	14.73	27.58

Attachment B-1. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		Date	Model Results-Outflow Temperature					
Model Reach	**Model Description**	**Month/ Day**	**Predicted Mean**	**Mean TOut -Mean TIn**	**Length Normalized Mean TOut -Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**	**(*F)**	**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 20 cfs					
BH18	existing conditions modeled	15-Jul	66.33	0.13	0.10	80.07	13.74	10.53
BH22	existing conditions modeled	15-Jul	68.10	1.90	0.31	82.80	14.70	2.41
BH22	vegetation changed to reference conditions	15-Jul	67.01	0.81	0.13	81.18	14.17	2.33
BH22	channel geometry changed to reference conditions	15-Jul	67.72	1.52	0.25	81.34	13.62	2.24
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	66.49	0.29	0.05	79.27	12.78	2.10
BH26	existing conditions modeled	15-Jul	67.50	1.30	0.50	82.54	15.04	5.76
BH26	vegetation changed to reference conditions	15-Jul	66.72	0.52	0.20	80.94	14.22	5.45
BH26	channel geometry changed to reference conditions	15-Jul	67.11	0.91	0.35	80.81	13.70	5.25
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	66.32	0.12	0.05	78.76	12.44	4.77
BH28	existing conditions modeled	15-Jul	66.30	0.10	0.19	80.35	14.05	26.31
BH28	vegetation changed to reference conditions	15-Jul	66.25	0.05	0.09	79.88	13.63	25.52

Attachment B-1. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Model Results-Outflow Temperature**					
Model Reach	**Model Description**	**Month /Day**	**Predicted Mean**	**Mean TOut - Mean TIn**	**Length Normalized Mean TOut -Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**	**(*F)**	**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 30 cfs					
BH18	existing conditions modeled	15-Jul	66.33	0.13	0.10	79.21	12.88	9.87
BH22	existing conditions modeled	15-Jul	67.87	1.67	0.27	81.81	13.94	2.29
BH22	vegetation changed to reference conditions	15-Jul	66.99	0.79	0.13	80.38	13.39	2.20
BH22	channel geometry changed to reference conditions	15-Jul	67.49	1.29	0.21	80.14	12.65	2.08
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	66.53	0.33	0.05	78.35	11.82	1.94
BH26	existing conditions modeled	15-Jul	67.25	1.05	0.40	81.45	14.20	5.44
BH26	vegetation changed to reference conditions	15-Jul	66.66	0.46	0.18	80.07	13.41	5.14
BH26	channel geometry changed to reference conditions	15-Jul	66.91	0.71	0.27	79.53	12.62	4.84
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	66.34	0.14	0.05	77.79	11.45	4.39
BH28	existing conditions modeled	15-Jul	66.29	0.09	0.17	79.43	13.14	24.61
BH28	vegetation changed to reference conditions	15-Jul	66.25	0.05	0.09	79.01	12.76	23.90

Attachment B-1. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Model Results-Outflow Temperature**					
Model Reach	**Model Description**		**Predicted Mean**	**Mean TOut - Mean TIn**	**Length Normalized Mean TOut -Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**		**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 40 cfs					
BH18	existing conditions modeled		66.32	0.12	0.09	78.52	12.20	9.35
BH22	existing conditions modeled		67.70	1.50	0.25	80.99	13.29	2.18
BH22	vegetation changed to reference conditions		66.96	0.76	0.12	79.69	12.73	2.09
BH22	channel geometry changed to reference conditions		67.32	1.12	0.18	79.21	11.89	1.95
BH22	vegetation & channel geometry changed to reference conditions		66.54	0.34	0.06	77.62	11.08	1.82
BH26	existing conditions modeled		67.08	0.88	0.34	80.59	13.51	5.18
BH26	vegetation changed to reference conditions		66.62	0.42	0.16	79.36	12.74	4.88
BH26	channel geometry changed to reference conditions		66.79	0.59	0.23	78.59	11.80	4.52
BH26	vegetation & channel geometry changed to reference conditions		66.34	0.14	0.05	77.05	10.71	4.10
BH28	existing conditions modeled		66.28	0.08	0.15	78.70	12.42	23.26
BH28	vegetation changed to reference conditions		66.25	0.05	0.09	78.31	12.06	22.58

Attachment B-1. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		Date	Model Results-Outflow Temperature					
Model Reach	**Model Description**	**Month/Day**	**Predicted Mean**	**Mean TOut -Mean TIn**	**Length Normalized Mean TOut -Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**		**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 50 cfs					
BH18	existing conditions modeled	15-Jul	66.32	0.12	0.09	77.95	11.63	8.91
BH22	existing conditions modeled	15-Jul	67.56	1.36	0.22	80.30	12.74	2.09
BH22	vegetation changed to reference conditions	15-Jul	66.92	0.72	0.12	79.11	12.19	2.00
BH22	channel geometry changed to reference conditions	15-Jul	67.21	1.01	0.17	78.48	11.27	1.85
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	66.54	0.34	0.06	77.04	10.50	1.72
BH26	existing conditions modeled	15-Jul	66.97	0.77	0.30	79.89	12.92	4.95
BH26	vegetation changed to reference conditions	15-Jul	66.58	0.38	0.15	78.77	12.19	4.67
BH26	channel geometry changed to reference conditions	15-Jul	66.71	0.51	0.20	77.85	11.14	4.27
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	66.34	0.14	0.05	76.46	10.12	3.88
BH28	existing conditions modeled	15-Jul	66.27	0.07	0.13	78.10	11.83	22.15
BH28	vegetation changed to reference conditions	15-Jul	66.25	0.05	0.09	77.74	11.49	21.52

Attachment B-1. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Model Results-Outflow Temperature**					
Model Reach	**Model Description**	**Month/ Day**	**Predicted Mean**	**Mean TOut - Mean TIn**	**Length Normalized Mean TOut - Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**		**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 60 cfs					
BH18	existing conditions modeled	15-Jul	66.32	0.12	0.09	77.47	11.15	8.54
BH22	existing conditions modeled	15-Jul	67.45	1.25	0.21	79.71	12.26	2.01
BH22	vegetation changed to reference conditions	15-Jul	66.89	0.69	0.11	78.61	11.72	1.92
BH22	channel geometry changed to reference conditions	15-Jul	67.11	0.91	0.15	77.87	10.76	1.77
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	66.54	0.34	0.06	76.55	10.01	1.64
BH26	existing conditions modeled	15-Jul	66.89	0.69	0.26	79.29	12.40	4.75
BH26	vegetation changed to reference conditions	15-Jul	66.56	0.36	0.14	78.26	11.70	4.48
BH26	channel geometry changed to reference conditions	15-Jul	66.66	0.46	0.18	77.25	10.59	4.06
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	66.34	0.14	0.05	75.98	9.64	3.69
BH28	existing conditions modeled	15-Jul	66.26	0.06	0.11	77.60	11.34	21.24
BH28	vegetation changed to reference conditions	15-Jul	66.24	0.04	0.07	77.25	11.01	20.62

Attachment B-1. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Model Results-Outflow Temperature**					
Model Reach	**Model Description**	**Month/Day**	**Predicted Mean**	**Mean TOut -Mean TIn**	**Length Normalized Mean TOut -Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**		**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 70 cfs					
BH18	existing conditions modeled	15-Jul	66.31	0.11	0.08	77.06	10.75	8.24
BH22	existing conditions modeled	15-Jul	67.36	1.16	0.19	79.20	11.84	1.94
BH22	vegetation changed to reference conditions	15-Jul	66.85	0.65	0.11	78.17	11.32	1.86
BH22	channel geometry changed to reference conditions	15-Jul	67.04	0.84	0.14	77.36	10.32	1.69
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	66.53	0.33	0.05	76.13	9.60	1.58
BH26	existing conditions modeled	15-Jul	66.82	0.62	0.24	78.79	11.97	4.59
BH26	vegetation changed to reference conditions	15-Jul	66.53	0.33	0.13	77.82	11.29	4.33
BH26	channel geometry changed to reference conditions	15-Jul	66.61	0.41	0.16	76.74	10.13	3.88
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	66.34	0.14	0.05	75.56	9.22	3.53
BH28	existing conditions modeled	15-Jul	66.26	0.06	0.11	77.17	10.91	20.43
BH28	vegetation changed to reference conditions	15-Jul	66.24	0.04	0.07	76.84	10.60	19.85

Attachment B-1. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Model Results-Outflow Temperature**					
Model Reach	**Model Description**	**Month/Day**	**Predicted Mean**	**Mean TOut -Mean TIn**	**Length Normalized Mean TOut -Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**		**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 80 cfs					
BH18	existing conditions modeled	15-Jul	66.31	0.11	0.08	76.70	10.39	7.96
BH22	existing conditions modeled	15-Jul	67.28	1.08	0.18	78.76	11.48	1.89
BH22	vegetation changed to reference conditions	15-Jul	66.83	0.63	0.10	77.79	10.96	1.80
BH22	channel geometry changed to reference conditions	15-Jul	66.98	0.78	0.13	76.92	9.94	1.63
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	66.52	0.32	0.05	75.77	9.25	1.52
BH26	existing conditions modeled	15-Jul	66.77	0.57	0.22	78.34	11.57	4.43
BH26	vegetation changed to reference conditions	15-Jul	66.51	0.31	0.12	77.44	10.93	4.19
BH26	channel geometry changed to reference conditions	15-Jul	66.58	0.38	0.15	76.32	9.74	3.73
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	66.33	0.13	0.05	75.21	8.88	3.40
BH28	existing conditions modeled	15-Jul	66.26	0.06	0.11	76.79	10.53	19.72
BH28	vegetation changed to reference conditions	15-Jul	66.24	0.04	0.07	76.48	10.24	19.18

Attachment B-1. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Model Results-Outflow Temperature**					
Model Reach	**Model Description**	**Month /Day**	**Predicted Mean**	**Mean TOut -Mean TIn**	**Length Normalized Mean TOut -Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**		**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 90 cfs					
BH18	existing conditions modeled	15-Jul	66.31	0.11	0.08	76.38	10.07	7.72
BH22	existing conditions modeled	15-Jul	67.21	1.01	0.17	78.36	11.15	1.83
BH22	vegetation changed to reference conditions	15-Jul	66.80	0.60	0.10	77.44	10.64	1.75
BH22	channel geometry changed to reference conditions	15-Jul	66.93	0.73	0.12	76.53	9.60	1.58
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	66.52	0.32	0.05	75.45	8.93	1.47
BH26	existing conditions modeled	15-Jul	66.73	0.53	0.20	77.95	11.22	4.30
BH26	vegetation changed to reference conditions	15-Jul	66.50	0.30	0.11	77.09	10.59	4.06
BH26	channel geometry changed to reference conditions	15-Jul	66.55	0.35	0.13	75.94	9.39	3.60
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	66.33	0.13	0.05	74.90	8.57	3.28
BH28	existing conditions modeled	15-Jul	66.25	0.05	0.09	76.46	10.21	19.12
BH28	vegetation changed to reference conditions	15-Jul	66.24	0.04	0.07	76.16	9.92	18.58

Attachment B-1. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Model Results-Outflow Temperature**					
Model Reach	**Model Description**	**Month /Day**	**Predicted Mean**	**Mean TOut - Mean TIn**	**Length Normalized Mean TOut - Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**		**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 100 cfs					
BH18	existing conditions modeled	15-Jul	66.30	0.10	0.08	76.09	9.79	7.50
BH22	existing conditions modeled	15-Jul	67.16	0.96	0.16	78.00	10.84	1.78
BH22	vegetation changed to reference conditions	15-Jul	66.78	0.58	0.10	77.13	10.35	1.70
BH22	channel geometry changed to reference conditions	15-Jul	66.89	0.69	0.11	76.19	9.30	1.53
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	66.51	0.31	0.05	75.17	8.66	1.42
BH26	existing conditions modeled	15-Jul	66.69	0.49	0.19	77.60	10.91	4.18
BH26	vegetation changed to reference conditions	15-Jul	66.48	0.28	0.11	76.79	10.31	3.95
BH26	channel geometry changed to reference conditions	15-Jul	66.53	0.33	0.13	75.61	9.08	3.48
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	66.33	0.13	0.05	74.62	8.29	3.18
BH28	existing conditions modeled	15-Jul	66.25	0.05	0.09	76.16	9.91	18.56
BH28	vegetation changed to reference conditions	15-Jul	66.24	0.04	0.07	75.87	9.63	18.03

APPENDIX C
DATA SUMMARY APPENDIX

Data Summary Appendix

Overview

This appendix consists of data summary tables not presented in any of the other appendices. Both temperature and sediment related data are contained within the tables of this appendix. For a full Microsoft Access database of data from this project contact Montana Department of Environmental Quality.

Table C-1. Percent Fines Less Than 2mm in Riffles

Stream Name	Reach Name	Reach Type	Zone	Percent < 2mm
Big Hole River	BH09	reference	Big Hole	0.0%
Big Hole River	BH18	reference	Big Hole	0.0%
Big Hole River	BH28	reference	Big Hole	7.9%
Johnson Creek	JC03	reference	Montane/high	34.0%
Schultz Creek	SH01	reference	Montane/high	13.3%
Warm Springs Creek	WS07	reference	Montane/high	2.0%
Trail Creek	TC02	reference	Montane/low	3.8%
Trail Creek	TC07	reference	Montane/low	22.5%
North Fork Big Hole River	NF02	reference	North Fork	14.1%
North Fork Big Hole River	NF06	reference	North Fork	4.8%
Fox Creek	FC03	reference	Valley	1.0%
Little Lake Creek	LL05	reference	Valley	38.2%
Mussigbrod Creek	MC05	reference	Valley	10.9%
Miner Creek	MC06	reference	Valley	20.0%
Pintlar Creek	PC04	reference	Valley	17.0%
Rock Creek	RO04	reference	Valley	19.4%
Big Hole River	BH08	Impacted	Big Hole	1.0%
Big Hole River	BH16	Impacted	Big Hole	5.0%
Big Hole River	BH19	Impacted	Big Hole	2.0%

Table C-1. Percent Fines Less Than 2mm in Riffles

Stream Name	Reach Name	Reach Type	Zone	Percent < 2mm
Big Hole River	BH22	Impacted	Big Hole	7.6%
Big Hole River	BH26	Impacted	Big Hole	0.0%
Big Hole River	BH26R	Impacted	Big Hole	3.0%
Johnson Creek	JC02	Impacted	Montane/high	13.0%
Johnson Creek	JC02R	Impacted	Montane/high	6.9%
Trail Creek	TC08	Impacted	Montane/high	19.4%
Trail Creek	TC08r	Impacted	Montane/high	22.5%
Frances Creek	FR01	Impacted	Montane/low	15.7%
Joseph Creek	JO02	Impacted	Montane/low	8.0%
Ruby Creek	RC04	Impacted	Montane/low	0.0%
Trail Creek	TC03	Impacted	Montane/low	27.5%
Tie Creek	TI02	Impacted	Montane/low	26.2%
North Fork Big Hole River	NF07	Impacted	North Fork	4.9%
North Fork Big Hole River	NF11	Impacted	North Fork	6.7%
Doolittle Creek	DC03	Impacted	Valley	23.0%
Fox Creek	FC02	Impacted	Valley	5.0%
Governor Creek	GC04	Impacted	Valley	8.2%
Governor Creek	GC06	Impacted	Valley	2.0%
Governor Creek	GC11	Impacted	Valley	0.0%
Johnson Creek	JC07	Impacted	Valley	5.0%
Mussigbrod Creek	MC07	Impacted	Valley	54.5%
McVey Creek	MV03	Impacted	Valley	60.0%
Pine Creek	PN03	Impacted	Valley	12.1%
Ruby Creek	RC07	Impacted	Valley	10.6%
Ruby Creek	RC08	Impacted	Valley	17.8%
Ruby Creek	RC08	Impacted	Valley	17.8%
Rock Creek	RO06	Impacted	Valley	13.2%
Steel Creek	SC03	Impacted	Valley	32.4%
Steel Creek	SC06	Impacted	Valley	25.5%
Swamp Creek	SW03	Impacted	Valley	20.8%

Table C-1. Percent Fines Less Than 2mm in Riffles

Stream Name	Reach Name	Reach Type	Zone	Percent < 2mm
Swamp Creek	SW10	Impacted	Valley	24.1%
Warm Springs Creek	WS10	Impacted	Valley	1.0%
Warm Springs Creek	WS11	Impacted	Valley	5.0%

Table C-2. Percent Fines Less Than 6mm in Riffles

Stream Name	Reach Name	Reach Type	Zone	Percent < 6mm
Big Hole River	BH09	reference	Big Hole	0.0%
Big Hole River	BH18	reference	Big Hole	0.0%
Big Hole River	BH28	reference	Big Hole	10.9%
Warm Springs Creek	WS07	reference	Montane/high	5.9%
Johnson Creek	JC03	reference	Montane/high	43.7%
Schultz Creek	SH01	reference	Montane/high	13.3%
Trail Creek	TC07	reference	Montane/low	34.3%
Trail Creek	TC02	reference	Montane/low	6.7%
North Fork Big Hole River	NF06	reference	North Fork	7.1%
North Fork Big Hole River	NF02	reference	North Fork	16.2%
Fox Creek	FC03	reference	Valley	1.0%
Rock Creek	RO04	reference	Valley	32.3%
Pintlar Creek	PC04	reference	Valley	18.9%
Miner Creek	MC06	reference	Valley	25.0%
Little Lake Creek	LL05	reference	Valley	41.2%
Mussigbrod Creek	MC05	reference	Valley	14.9%
Big Hole River	BH19	Impacted	Big Hole	7.0%
Big Hole River	BH22	Impacted	Big Hole	8.7%
Big Hole River	BH26	Impacted	Big Hole	2.8%
Big Hole River	BH08	Impacted	Big Hole	6.0%
Big Hole River	BH16	Impacted	Big Hole	8.0%
Big Hole River	BH26R	Impacted	Big Hole	7.9%
Johnson Creek	JC02R	Impacted	Montane/high	10.9%

Table C-2. Percent Fines Less Than 6mm in Riffles

Stream Name	Reach Name	Reach Type	Zone	Percent < 6mm
Johnson Creek	JC02	Impacted	Montane/high	21.0%
Trail Creek	TC08r	Impacted	Montane/high	28.4%
Trail Creek	TC08	Impacted	Montane/high	29.1%
Joseph Creek	JO02	Impacted	Montane/low	15.0%
Trail Creek	TC03	Impacted	Montane/low	42.2%
Tie Creek	TI02	Impacted	Montane/low	32.7%
Ruby Creek	RC04	Impacted	Montane/low	2.0%
Frances Creek	FR01	Impacted	Montane/low	17.6%
North Fork Big Hole River	NF07	Impacted	North Fork	7.8%
North Fork Big Hole River	NF11	Impacted	North Fork	8.7%
Doolittle Creek	DC03	Impacted	Valley	33.0%
Johnson Creek	JC07	Impacted	Valley	5.0%
Governor Creek	GC06	Impacted	Valley	2.0%
Governor Creek	GC11	Impacted	Valley	0.0%
Governor Creek	GC04	Impacted	Valley	9.2%
Fox Creek	FC02	Impacted	Valley	6.0%
Pine Creek	PN03	Impacted	Valley	13.1%
McVey Creek	MV03	Impacted	Valley	67.0%
Mussigbrod Creek	MC07	Impacted	Valley	71.3%
Swamp Creek	SW10	Impacted	Valley	26.9%
Swamp Creek	SW03	Impacted	Valley	24.8%
Ruby Creek	RC08	Impacted	Valley	25.7%
Ruby Creek	RC07	Impacted	Valley	15.4%
Steel Creek	SC06	Impacted	Valley	26.5%
Warm Springs Creek	WS11	Impacted	Valley	10.9%
Warm Springs Creek	WS10	Impacted	Valley	1.0%
Steel Creek	SC03	Impacted	Valley	51.9%
Rock Creek	RO06	Impacted	Valley	20.2%
Ruby Creek	RC08	Impacted	Valley	25.7%

Table C-3. Area of Eroding Banks Along Each Monitoring Reach (sq. ft)

			Eroding Bank #							
Reach Name	**Reach Type**	**Zone**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
BH09	reference	Big Hole	92	185	80	136				
BH28	reference	Big Hole	148							
JC03	reference	Montane/high	70							
WS07	reference	Montane/high	37	35	15	14	42	100		
TC02	reference	Montane/low	36							
TC07	reference	Montane/low	36							
NF02	reference	North Fork	176							
NF06	reference	North Fork	70	50	38	67				
FC03	reference	Valley	35							
MC05	reference	Valley	60							
PC04R	reference	Valley	24	125	122	26				
RO04	reference	Valley	31							
BH08	Impacted	Big Hole	56	86	210	76	258	294	276	
BH16	Impacted	Big Hole	130	51	68					
BH19	Impacted	Big Hole	392	473	443	360	233	231		
BH26	Impacted	Big Hole	281							
BH26R	Impacted	Big Hole	512	108						
TC08	Impacted	Montane/high	175	152						
RC04	Impacted	Montane/low	38	18	39					
TC03	Impacted	Montane/low	112	71						
TI02	Impacted	Montane/low	33	128						
NF07	Impacted	North Fork	51	260	113	83	990			
NF11	Impacted	North Fork	69	950	630	178				
DC03	Impacted	Valley	225	495	374					
GC04	Impacted	Valley	12	32	36	54	14			
GC06	Impacted	Valley	94	32	57	22	146			
GC11	Impacted	Valley	156	272	87	105	148	71		
JC07	Impacted	Valley	35	86						

Table C-3. Area of Eroding Banks Along Each Monitoring Reach (sq. ft)

			Eroding Bank #							
Reach Name	**Reach Type**	**Zone**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
MC07	Impacted	Valley	60	34	32					
MV03	Impacted	Valley	34	179	24	40	27	36	18	42
PN03	Impacted	Valley	26	32						
RC07	Impacted	Valley	228	42	50	141	32	166	210	
RC08	Impacted	Valley	13	29	43	110				
RO06	Impacted	Valley	44	60	20	26				
SC03	Impacted	Valley	95	20	60	36	48			
SC06	Impacted	Valley	87	385	122	224				
SW10	Impacted	Valley	70	52	113	215	97	98	50	630
WS10	Impacted	Valley	29	344	100	136				
WS11	Impacted	Valley	48	554	53	156	710	92	220	

Table C-4. Area of Eroding Banks Along Each Monitoring Reach (sq. ft)

			Eroding Bank #								
Reach_Name	**Reach_Type**	**Zone**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**total**
BH09	reference	Big Hole									493
BH28	reference	Big Hole									148
JC03	reference	Montane/high									70
WS07	reference	Montane/high									243
TC02	reference	Montane/low									36
TC07	reference	Montane/low									36
NF02	reference	North Fork									176
NF06	reference	North Fork									224
FC03	reference	Valley									35
MC05	reference	Valley									60
PC04R	reference	Valley									297
RO04	reference	Valley									31
BH08	Impacted	Big Hole									1256
BH16	Impacted	Big Hole									249
BH19	Impacted	Big Hole									2132
BH26	Impacted	Big Hole									281
BH26R	Impacted	Big Hole									620
TC08	Impacted	Montane/high									327
RC04	Impacted	Montane/low									95
TC03	Impacted	Montane/low									183
TI02	Impacted	Montane/low									161
NF07	Impacted	North Fork									1497
NF11	Impacted	North Fork									1827
DC03	Impacted	Valley									1094
GC04	Impacted	Valley									149
GC06	Impacted	Valley									350
GC11	Impacted	Valley									840

Table C-4. Area of Eroding Banks Along Each Monitoring Reach (sq. ft)

			Eroding Bank #								
Reach_Name	**Reach_Type**	**Zone**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**total**
JC07	Impacted	Valley									122
MC07	Impacted	Valley									126
MV03	Impacted	Valley	77	96	96	42	20	66	66	40	902
PN03	Impacted	Valley									59
RC07	Impacted	Valley									869
RC08	Impacted	Valley									196
RO06	Impacted	Valley									150
SC03	Impacted	Valley									259
SC06	Impacted	Valley									818
SW10	Impacted	Valley	60	240							1624
WS10	Impacted	Valley									608
WS11	Impacted	Valley									1834

Table C-5. Percent fines less than 6 mm in pool tails

Reach Name	Reach Type	Zone	Fines Score	Pool#
BH08	Impacted	Big Hole	1.53	1
BH08	Impacted	Big Hole	9.69	2
BH08	Impacted	Big Hole	6.12	3
BH16	Impacted	Big Hole	9.69	1
BH16	Impacted	Big Hole	19.39	2
BH19	Impacted	Big Hole	15.82	1
BH22	Impacted	Big Hole	37.76	1
BH22	Impacted	Big Hole	57.65	2
BH22	Impacted	Big Hole	62.24	3
BH22	Impacted	Big Hole	56.63	4
BH26	Impacted	Big Hole	12.24	1
BH26R	Impacted	Big Hole	100.00	1

Table C-5. Percent fines less than 6 mm in pool tails

Reach Name	Reach Type	Zone	Fines Score	Pool#
DC03	Impacted	Valley	97.96	1
DC03	Impacted	Valley	54.59	2
DC03	Impacted	Valley	94.39	3
DC03	Impacted	Valley	46.94	4
DC03	Impacted	Valley	4.08	5
DC03	Impacted	Valley	34.69	6
DC03	Impacted	Valley	39.29	7
DC03	Impacted	Valley	96.43	8
DC03	Impacted	Valley	89.80	9
DC03	Impacted	Valley	9.69	10
DC03	Impacted	Valley	55.61	11
DC03	Impacted	Valley	71.43	12
FC02	Impacted	Valley	61.73	1
FC02	Impacted	Valley	59.18	2
FC02	Impacted	Valley	75.00	3
FC02	Impacted	Valley	93.88	4
FC02	Impacted	Valley	46.94	5
FR01	Impacted	Montane/low	67.86	1
FR01	Impacted	Montane/low	84.18	2
FR01	Impacted	Montane/low	94.39	3
GC04	Impacted	Valley	100.00	1
GC04	Impacted	Valley	96.43	2
GC04	Impacted	Valley	89.29	3
GC04	Impacted	Valley	94.39	4
GC04	Impacted	Valley	99.49	5
GC04	Impacted	Valley	93.37	6
GC04	Impacted	Valley	95.41	7
GC04	Impacted	Valley	88.78	8
GC06	Impacted	Valley	98.47	1
GC06	Impacted	Valley	86.73	2

Table C-5. Percent fines less than 6 mm in pool tails

Reach Name	Reach Type	Zone	Fines Score	Pool#
GC06	Impacted	Valley	79.59	3
GC06	Impacted	Valley	77.04	4
GC06	Impacted	Valley	34.18	5
GC06	Impacted	Valley	75.51	6
GC06	Impacted	Valley	93.37	7
GC11	Impacted	Valley	8.16	1
GC11	Impacted	Valley	2.55	2
JC02	Impacted	Montane/high	85.71	1
JC02	Impacted	Montane/high	76.53	2
JC02	Impacted	Montane/high	51.02	3
JC02	Impacted	Montane/high	5.61	4
JC02R	Impacted	Montane/high	3.06	1
JC02R	Impacted	Montane/high	0.00	2
JC02R	Impacted	Montane/high	15.31	3
JC07	Impacted	Valley	64.80	1
JC07	Impacted	Valley	40.82	2
JC07	Impacted	Valley	50.51	3
JO02	Impacted	Montane/low	51.02	1
JO02	Impacted	Montane/low	63.78	2
JO02	Impacted	Montane/low	48.47	3
JO02	Impacted	Montane/low	10.20	4
JO02	Impacted	Montane/low	30.61	5
MC07	Impacted	Valley	67.35	1
MC07	Impacted	Valley	100.00	2
MV03	Impacted	Valley	100.00	1
MV03	Impacted	Valley	100.00	2
NF07	Impacted	North Fork	38.78	1
NF11	Impacted	North Fork	100.00	1
PN03	Impacted	Valley	28.57	1
PN03	Impacted	Valley	89.29	2

Table C-5. Percent fines less than 6 mm in pool tails

Reach Name	Reach Type	Zone	Fines Score	Pool#
PN03	Impacted	Valley	100.00	3
PN03	Impacted	Valley	85.20	4
PN03	Impacted	Valley	91.84	5
RC04	Impacted	Montane/low	6.12	1
RC04	Impacted	Montane/low	1.02	2
RC04	Impacted	Montane/low	6.12	3
RC04	Impacted	Montane/low	1.02	4
RC07	Impacted	Valley	34.69	1
RC07	Impacted	Valley	64.80	2
RC08	Impacted	Valley	55.61	1
RC08	Impacted	Valley	35.71	2
RC08	Impacted	Valley	52.04	3
RC08	Impacted	Valley	59.18	4
RO06	Impacted	Valley	95.92	1
RO06	Impacted	Valley	100.00	2
SC03	Impacted	Valley	60.71	1
SC03	Impacted	Valley	93.88	2
SC06	Impacted	Valley	38.27	1
SC06	Impacted	Valley	54.08	2
SW03	Impacted	Valley	97.96	1
SW03	Impacted	Valley	50.00	2
SW03	Impacted	Valley	91.33	3
SW10	Impacted	Valley	28.06	1
SW10	Impacted	Valley	4.08	2
TC03	Impacted	Montane/low	50.51	1
TC03	Impacted	Montane/low	5.10	2
TC03	Impacted	Montane/low	23.47	3
TC08	Impacted	Montane/high	17.35	1
TC08	Impacted	Montane/high	56.12	2
TI02	Impacted	Montane/low	2.55	1

Table C-5. Percent fines less than 6 mm in pool tails

Reach Name	Reach Type	Zone	Fines Score	Pool#
TI02	Impacted	Montane/low	9.18	2
TI02	Impacted	Montane/low	62.76	3
WS10	Impacted	Valley	8.16	1
WS10	Impacted	Valley	4.08	2
WS11	Impacted	Valley	2.04	1
WS11	Impacted	Valley	14.80	2
BH09	reference	Big Hole	4.59	1
BH09	reference	Big Hole	2.55	2
BH18	reference	Big Hole	98.47	1
BH18	reference	Big Hole	12.76	2
BH18	reference	Big Hole	9.69	3
BH18	reference	Big Hole	10.71	4
BH18	reference	Big Hole	5.10	5
BH28	reference	Big Hole	25.00	1
BH28	reference	Big Hole	59.18	2
BH28	reference	Big Hole	46.43	3
BH28	reference	Big Hole	100.00	4
BH28	reference	Big Hole	50.00	5
BH28	reference	Big Hole	19.90	6
BH28	reference	Big Hole	100.00	7
FC03	reference	Valley	18.37	1
FC03	reference	Valley	12.24	2
FC03	reference	Valley	25.00	3
FC03	reference	Valley	55.61	4
FC03	reference	Valley	16.33	5
FC03	reference	Valley	81.63	6
FC03	reference	Valley	66.33	7
FC03	reference	Valley	89.80	8
FC03	reference	Valley	16.33	9
FC03	reference	Valley	56.12	10

Table C-5. Percent fines less than 6 mm in pool tails

Reach Name	Reach Type	Zone	Fines Score	Pool#
FC03	reference	Valley	46.94	11
FC03	reference	Valley	13.27	12
JC03	reference	Montane/high	92.35	1
JC03	reference	Montane/high	99.49	2
JC03	reference	Montane/high	98.98	3
LL05	reference	Valley	88.78	1
LL05	reference	Valley	88.27	2
LL05	reference	Valley	91.84	3
LL05	reference	Valley	97.96	4
LL05	reference	Valley	92.35	5
LL05	reference	Valley	72.45	6
LL05	reference	Valley	95.41	7
LL05	reference	Valley	100.00	8
MC05	reference	Valley	79.59	1
MC05	reference	Valley	12.24	2
MC06	reference	Valley	91.33	1
MC06	reference	Valley	94.90	2
MC06	reference	Valley	100.00	3
MC06	reference	Valley	100.00	4
MC06	reference	Valley	99.49	5
MC06	reference	Valley	100.00	6
MC06	reference	Valley	100.00	7
MC06	reference	Valley	100.00	8
MC06	reference	Valley	81.63	9
NF02	reference	North Fork	10.71	1
NF02	reference	North Fork	11.22	2
NF06	reference	North Fork	38.27	1
PC04	reference	Valley	99.49	1
PC04	reference	Valley	11.22	2
PC04	reference	Valley	80.61	3

Table C-5. Percent fines less than 6 mm in pool tails

Reach Name	Reach Type	Zone	Fines Score	Pool#
PC04	reference	Valley	100.00	4
PC04	reference	Valley	73.47	5
PC04R	reference	Valley	64.29	1
RO04	reference	Valley	62.24	1
RO04	reference	Valley	20.41	2
RO04	reference	Valley	9.69	3
RO04	reference	Valley	24.49	4
RO04	reference	Valley	32.65	5
SC02	reference	Montane/low	100.00	1
SH01	reference	Montane/high	14.29	1
SH01	reference	Montane/high	6.12	2
SH01	reference	Montane/high	7.14	3
SH01	reference	Montane/high	2.04	4
SH01	reference	Montane/high	3.57	5
SH01	reference	Montane/high	10.20	6
SH01	reference	Montane/high	43.88	7
SH01	reference	Montane/high	8.16	8
TC02	reference	Montane/low	79.59	1
TC02	reference	Montane/low	50.51	2
TC02	reference	Montane/low	12.76	3
TC02	reference	Montane/low	42.35	4
TC07	reference	Montane/low	100.00	1
TC07	reference	Montane/low	92.35	2
TC07	reference	Montane/low	50.51	3
TC07	reference	Montane/low	18.88	4
WS07	reference	Montane/high	39.29	1
WS07	reference	Montane/high	12.76	2
WS07	reference	Montane/high	2.55	3
WS07	reference	Montane/high	0.00	4

Table C-6. Pool Frequency

Bankfull Widths/Pool				
Stream Name	**Reach Name**	**Reach Type**	**Zone**	**Bankfull Width/Pool**
Big Hole River	BH18	reference	Big Hole	5.55
Big Hole River	BH28	reference	Big Hole	2.97
Big Hole River	BH09	reference	Big Hole	4.74
Johnson Creek	JC03	reference	Montane/high	4.61
Warm Springs Creek	WS07	reference	Montane/high	2.83
Schultz Creek	SH01	reference	Montane/high	5.02
Trail Creek	TC02	reference	Montane/low	4.75
Trail Creek	TC07	reference	Montane/low	6.03
North Fork Big Hole River	NF02	reference	North Fork	5.43
North Fork Big Hole River	NF06	reference	North Fork	7.51
Fox Creek	FC03	reference	Valley	8.35
Miner Creek	MC06	reference	Valley	4.92
Pintlar Creek	PC04	reference	Valley	7.26
Pintlar Creek	PC04R	reference	Valley	15.21
Mussigbrod Creek	MC05	reference	Valley	21.80
Rock Creek	RO04	reference	Valley	5.43
Little Lake Creek	LL05	reference	Valley	4.69
Big Hole River	BH22	Impacted	Big Hole	4.80
Big Hole River	BH26	Impacted	Big Hole	16.45
Big Hole River	BH16	Impacted	Big Hole	7.39
Big Hole River	BH19	Impacted	Big Hole	13.20
Big Hole River	BH26R	Impacted	Big Hole	12.17
Big Hole River	BH08	Impacted	Big Hole	3.66
Johnson Creek	JC02	Impacted	Montane/high	4.73
Trail Creek	TC08	Impacted	Montane/high	8.77
Johnson Creek	JC02R	Impacted	Montane/high	6.39
Joseph Creek	JO02	Impacted	Montane/low	3.89
Ruby Creek	RC04	Impacted	Montane/low	4.95

Table C-6. Pool Frequency

Bankfull Widths/Pool				
Stream Name	**Reach Name**	**Reach Type**	**Zone**	**Bankfull Width/Pool**
Tie Creek	TI02	Impacted	Montane/low	5.30
Trail Creek	TC03	Impacted	Montane/low	8.33
Frances Creek	FR01	Impacted	Montane/low	11.84
North Fork Big Hole River	NF11	Impacted	North Fork	16.98
North Fork Big Hole River	NF07	Impacted	North Fork	7.51
Doolittle Creek	DC03	Impacted	Valley	6.03
Fox Creek	FC02	Impacted	Valley	23.54
Governor Creek	GC04	Impacted	Valley	9.98
Governor Creek	GC06	Impacted	Valley	10.12
McVey Creek	MV03	Impacted	Valley	71.18
Pine Creek	PN03	Impacted	Valley	17.18
Warm Springs Creek	WS11	Impacted	Valley	5.87
Steel Creek	SC06	Impacted	Valley	9.79
Steel Creek	SC03	Impacted	Valley	20.86
Johnson Creek	JC07	Impacted	Valley	8.60
Warm Springs Creek	WS10	Impacted	Valley	6.87
Ruby Creek	RC07	Impacted	Valley	6.14
Ruby Creek	RC08	Impacted	Valley	4.46
Governor Creek	GC11	Impacted	Valley	7.32
Swamp Creek	SW03	Impacted	Valley	13.47
Swamp Creek	SW10	Impacted	Valley	6.48
Mussigbrod Creek	MC07	Impacted	Valley	25.25
Rock Creek	RO06	Impacted	Valley	13.34

Table C-7. Percent Shrub Cover Along Stream Banks

			Percent Shrub Cover Along Bankfull			
Reach Name	**Reach Type**	**Zone**	**Score 1**	**Score 2**	**Score 3**	**Score 4**
WS11	Impacted	Valley	58	60	32	38
WS10	Impacted	Valley	62	38	54	68
WS07	reference	Montane/high	76	68	82	82
TI02	Impacted	Montane/low	46	50	52	68
TC08r	Impacted	Montane/high	12	36	2	0
TC08	Impacted	Montane/high	32	68	56	56
TC07	reference	Montane/low	42	50	38	26
TC03	Impacted	Montane/low	46	34	44	54
TC02	reference	Montane/low	40	36	32	36
SW10	Impacted	Valley	2	6	2	0
SW03	Impacted	Valley	36	38	48	48
SH01	reference	Montane/high	2	0	0	0
SC06	Impacted	Valley	0	0	2	0
SC03	Impacted	Valley	60	46	50	64
SC02	reference	Montane/low	80	76	72	76
RO06	Impacted	Valley	24	30	14	8
RO04	reference	Valley	10	26	24	20
RC08	Impacted	Valley	30	38	56	60
RC07	Impacted	Valley	72	58	56	40
RC04	Impacted	Montane/low	34	60	56	32
PN03	Impacted	Valley	28	50	26	44
PC04R	reference	Valley	78	58	72	84
PC04	reference	Valley	84	78	48	38
NF11	Impacted	North Fork	14	0	0	2
NF07	Impacted	North Fork	2	8	26	16
NF06	reference	North Fork	48	34	24	38
NF02	reference	North Fork	54	62	36	48
MV03	Impacted	Valley	0	0	0	0

Table C-7. Percent Shrub Cover Along Stream Banks

			Percent Shrub Cover Along Bankfull			
Reach Name	**Reach Type**	**Zone**	**Score 1**	**Score 2**	**Score 3**	**Score 4**
MC07	Impacted	Valley	52	38	48	38
MC06	reference	Valley	48	44	54	68
MC05	reference	Valley	22	26	66	78
LL05	reference	Valley	34	18	64	58
JO02	Impacted	Montane/low	58	60	70	58
JC07	Impacted	Valley	68	46	52	66
JC03	reference	Montane/high	0	0	0	0
JC02R	Impacted	Montane/high	6	4	2	10
JC02	Impacted	Montane/high	0	0	0	0
GC11	Impacted	Valley	24	40	20	28
GC06	Impacted	Valley	36	30	40	28
GC04	Impacted	Valley	0	0	0	0
FR01	Impacted	Montane/low	0	0	0	0
FC03	reference	Valley	66	72	62	82
FC02	Impacted	Valley	18	36	54	68
DC03	Impacted	Valley	6	6	14	12
BH28	reference	Big Hole	26	40	22	10
BH26R	Impacted	Big Hole	0	4	10	0
BH26	Impacted	Big Hole	0	0	6	0
BH22	Impacted	Big Hole	6	18	10	8
BH19	Impacted	Big Hole	18	26	18	2
BH18	reference	Big Hole	72	60	32	38
BH16	Impacted	Big Hole	30	6	40	42
BH09	reference	Big Hole	74	60	76	86
BH08	Impacted	Big Hole	32	22	20	40

Table C-8. Percent Shrub Cover along Perpendicular Transects to Stream

			% Cover Along Transects				
Reach Name	**Reach Type**	**Zone**	**Score A**	**Score B**	**Score C**	**Score D**	**Score E**
BH18	reference	Big Hole	65.5	98.0	74.7	57.0	21.5
BH28	reference	Big Hole	27.0	30.7	33.1	55.4	3.0
BH09	reference	Big Hole	93.1	62.4	91.6	67.7	54.1
JC03	reference	Montane/high	0.0	0.0	0.0	0.0	0.0
WS07	reference	Montane/high	79.9	60.9	77.6	81.3	66.9
SH01	reference	Montane/high	0.0	0.0	0.0	0.0	0.0
SC02	reference	Montane/low	25.6	78.3	84.3	76.3	95.0
TC02	reference	Montane/low	64.1	45.5	48.8	25.0	28.4
TC07	reference	Montane/low	86.6	68.1	61.9	67.8	50.0
NF02	reference	North Fork	35.7	50.2	45.6	20.0	85.0
NF06	reference	North Fork	69.5	54.0	84.6	62.0	35.5
FC03	reference	Valley	21.6	54.5	62.5	48.6	51.5
MC06	reference	Valley	45.0	75.5	89.0	58.0	85.5
PC04	reference	Valley	86.4	78.6	84.3	58.2	89.7
PC04R	reference	Valley	76.6	82.5	90.1	40.8	48.9
MC05	reference	Valley	17.8	10.4	11.7	9.0	15.7
RO04	reference	Valley	44.4	50.7	32.4	74.0	37.4
LL05	reference	Valley	10.0	4.0	36.0	14.5	17.0
BH22	Impacted	Big Hole	21.9	25.8	30.8	25.9	0.0
BH26	Impacted	Big Hole	0.0	0.0	16.0	0.0	0.0
BH16	Impacted	Big Hole	1.5	16.0	0.0	11.0	46.1
BH19	Impacted	Big Hole	12.7	10.5	0.0	10.3	0.0
BH26R	Impacted	Big Hole	20.0	0.0	86.5	50.0	0.0
BH08	Impacted	Big Hole	40.1	34.7	27.5	0.0	34.5
JC02	Impacted	Montane/high	0.0	0.0	0.0	0.0	0.0
TC08	Impacted	Montane/high	44.2	54.4	0.0	27.3	73.7
TC08r	Impacted	Montane/high	0.0	56.3	58.0		
JC02R	Impacted	Montane/high	0.0	0.0	0.0	0.0	0.0

Table C-8. Percent Shrub Cover along Perpendicular Transects to Stream

			% Cover Along Transects				
Reach Name	**Reach Type**	**Zone**	**Score A**	**Score B**	**Score C**	**Score D**	**Score E**
JO02	Impacted	Montane/low	87.9	36.0	91.5	68.1	68.3
RC04	Impacted	Montane/low	58.2	53.2	54.0	80.3	54.6
TI02	Impacted	Montane/low	39.8	44.6	35.3	62.9	72.9
TC03	Impacted	Montane/low	69.5	57.9	30.8	48.0	85.0
FR01	Impacted	Montane/low	0.0	44.6	0.0	0.0	0.0
NF11	Impacted	North Fork	29.2	0.0	32.5	0.0	18.0
NF07	Impacted	North Fork	36.5	7.7	64.7	24.6	32.7
DC03	Impacted	Valley	1.0	0.0	1.0	4.8	0.0
FC02	Impacted	Valley	5.4	9.4	44.6	11.3	0.0
GC04	Impacted	Valley	0.0	0.0	0.0	0.0	0.0
GC06	Impacted	Valley	40.1	0.0	41.5	7.0	37.2
MV03	Impacted	Valley	0.0	0.0	0.0	0.0	0.0
PN03	Impacted	Valley	16.9	36.7	16.7	71.1	10.8
WS11	Impacted	Valley	90.8	88.2	6.1	82.9	69.6
SC06	Impacted	Valley	0.8	0.0	0.0	0.0	0.0
SC03	Impacted	Valley			0.0	30.4	100.0
JC07	Impacted	Valley	16.0	70.5	40.3	35.5	23.8
WS10	Impacted	Valley	86.3	41.0	81.0	0.0	54.0
RC07	Impacted	Valley	75.4	52.9	73.3	67.2	45.3
RC08	Impacted	Valley	46.2	65.6	56.7	72.7	95.9
GC11	Impacted	Valley	43.5	72.6	38.5	25.9	33.6
SW03	Impacted	Valley	45.0	33.5	13.8	36.6	54.9
SW10	Impacted	Valley	0.0	0.0	11.3	0.0	0.8
MC07	Impacted	Valley	27.6	0.0	0.0	0.0	0.0
RO06	Impacted	Valley	12.2	8.3	6.1	46.9	0.0

Table C-9. Width to Depth Ratios

Reach	Transect	Channel Characteristics at Cross	Width/Depth
BH18	A	LS	22
BH18	B	LS	33
BH18	C	LS/R	27
BH18	D	LS	43
BH18	E	RI	22
BH28	A	GL	20
BH28	B	RI	22
BH28	C	MCP	22
BH28	D	PL	12
BH28	E	PL	8
BH09	A	RUN	11
BH09	B	RUN	21
BH09	C	GL	22
BH09	D	RUN	25
BH09	E	RUN	31
BH22	A	RI	34
BH22	B	GL	31
BH22	C	RI	35
BH22	D	PL	10
BH22	E	PL	59
BH26	A	RI	46
BH26	B	GL	58
BH26	C	RI	59
BH26	D	RI	82
BH26	E	GL	68
BH16	A	GL	39
BH16	B	RUN	18
BH16	C	GL	25
BH16	D	MCP	4

Table C-9. Width to Depth Ratios

Reach	Transect	Channel Characteristics at Cross	Width/Depth
BH16	E	RUN	34
BH19	A	RI	68
BH19	B	MCP	55
BH19	C	MCP	44
BH19	D	GL	32
BH19	E	RUN	44
BH26R	A	GL	71
BH26R	B	GL	58
BH26R	C	PL	56
BH26R	D	GL	42
BH26R	E	RUN	48
BH08	A	PL	22
BH08	B	PL	34
BH08	C	RI	55
BH08	D	RUN	51
BH08	E	RUN	70
NF02	A	RI	22
NF02	B	PB	10
NF02	C	RI	25
NF02	D	GL	28
NF02	E	PB	16
NF06	A	RUN	26
NF06	B	RUN	16
NF06	C	RI	29
NF06	D	RUN	30
NF06	E	PL	20
JC03	A	PD	12
JC03	B	PD	8
JC03	C	RUN	42
JC03	D	PD	9

Table C-9. Width to Depth Ratios

Reach	Transect	Channel Characteristics at Cross	Width/Depth
JC03	E	RUN	23
SH01	A	GL	13
SH01	B	GL	15
SH01	C	PP	6
SH01	D	PP	6
SH01	E	PP	13
TC02	A	PL	4
TC02	B	PL	13
TC02	C	RI	13
TC02	D	MP	10
TC02	E	PD	5
TC07	A	CCP	10
TC07	B	MCP	8
TC07	C	RI	11
TC07	D	PD	16
TC07	E	PD	9
FC03	A	RUN	5
FC03	B	GL	14
FC03	C	RI	13
FC03	D	RUN	16
FC03	E	RI	19
LL05	A	RI	30
LL05	B	PL	8
LL05	C	GL	10
LL05	D	PL	20
LL05	E	GL	19
MC05	A	RI	22
MC05	B	PB	10
MC05	C	RI	25
MC05	D	GL	28

Table C-9. Width to Depth Ratios

Reach	Transect	Channel Characteristics at Cross	Width/Depth
MC05	E	PB	16
MC06	A	RI	14
MC06	B	LS	6
MC06	C	RI	15
MC06	D	RI	14
MC06	A	PI	4
NF02	B	RUN	9
NF02	C	RUN	8
NF02	D	RI	11
NF02	E	RI	11
NF02	A	RUN	26
NF06	B	RUN	16
NF06	C	RI	29
NF06	D	RUN	30
NF06	E	PL	20
NF06	A	MCP	11
PC04	B	RI	21
PC04	C	GL	10
PC04	D	RUN	5
PC04	E	RI	12
PC04R	A	RI	13
PC04R	B	RI	8
PC04R	C	RI	8
PC04R	D	GL	16
PC04R	E	PL	5
PC04	A	RI	14
PC04	B	LS	6
PC04	C	RI	15
PC04	D	RI	14
PC04R	A	PI	4

Table C-9. Width to Depth Ratios

Reach	Transect	Channel Characteristics at Cross	Width/Depth
PC04R	B	RUN	9
PC04R	C	RUN	8
PC04R	D	RI	11
PC04R	E	RI	11

Table C-10. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		Date	Geometry						
Model Reach	Model Description	Month/ day	Latitude	Segment Length	Upstream Elevation	Downstream Elevation	Width's A Term	Width's B Term	Manning's n
(--)	(--)		(degrees)	(mi)	(ft)	(ft)	(s/ft2)	(--)	(--)
BH18	existing conditions modeled	15-Jul	45.399	1.305	6400.89	6361.52	17.603	0.2	0.045
BH22	existing conditions modeled	15-Jul	45.502	6.089	6259.82	6171.24	26.561	0.2	0.041
BH22	vegetation changed to reference conditions	15-Jul	45.502	6.089	6259.82	6171.24	26.561	0.2	0.041
BH22	channel geometry changed to reference conditions	15-Jul	45.502	6.089	6259.82	6171.24	17.45	0.2	0.041
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	45.502	6.089	6259.82	6171.24	17.45	0.2	0.041
BH26	existing conditions modeled	15-Jul	45.639	2.61	6040	6003.91	27.049	0.2	0.042
BH26	vegetation changed to reference conditions	15-Jul	45.639	2.61	6040	6003.91	27.049	0.2	0.042
BH26	channel geometry changed to reference conditions	15-Jul	45.639	2.61	6040	6003.91	16.56	0.2	0.042
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	45.639	2.61	6040	6003.91	16.56	0.2	0.042
BH28	existing conditions modeled	15-Jul	45.662	0.534	5974.39	5961.26	17.625	0.2	0.039
BH28	vegetation changed to reference conditions	15-Jul	45.662	0.534	5974.39	5961.26	17.625	0.2	0.039

Table C-11. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Hydrology**			
Model Reach	**Model Description**	**month / day**	**Segment Inflow**	**Inflow Temp.**	**Segment Outflow**	**Accretion Temp.**
(--)	**(--)**	**(--)**	**(cfs)**	**(*F)**	**(cfs)**	**(*F)**
BH18	existing conditions modeled	15-Jul	20	66.2	20	42.4
BH22	existing conditions modeled	15-Jul	20	66.2	20	42.4
BH22	vegetation changed to reference conditions	15-Jul	20	66.2	20	42.4
BH22	channel geometry changed to reference conditions	15-Jul	20	66.2	20	42.4
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	20	66.2	20	42.4
BH26	existing conditions modeled	15-Jul	20	66.2	20	42.4
BH26	vegetation changed to reference conditions	15-Jul	20	66.2	20	42.4
BH26	channel geometry changed to reference conditions	15-Jul	20	66.2	20	42.4
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	20	66.2	20	42.4
BH28	existing conditions modeled	15-Jul	20	66.2	20	42.4
BH28	vegetation changed to reference conditions	15-Jul	20	66.2	20	42.4

Table C-12. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Meteorology**								
Model Reach	**Model Description**	**Month / Day**	**Air Temp.**	**Max. Air Temp**	**Relative Humidity**	**Wind Speed**	**Ground Temp**	**Thermal Gradient**	**Possible Sun**	**Dust Coeff.**	**Ground Reflectivity**
(--)	**(--)**	**(…)**	**(*F)**	**(*F)**	**(%)**	**(mph)**	**(*F)**	**(j/m2/s/C)**	**(%)**	**(--)**	**(%)**
BH18	existing conditions modeled	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14
BH22	existing conditions modeled	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14
BH22	vegetation changed to reference conditions	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14
BH22	channel geometry changed to reference conditions	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14
BH26	existing conditions modeled	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14
BH26	vegetation changed to reference	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14

Table C-12. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Meteorology**								
Model Reach	**Model Description**	**Month / Day**	**Air Temp.**	**Max. Air Temp**	**Relative Humidity**	**Wind Speed**	**Ground Temp**	**Thermal Gradient**	**Possible Sun**	**Dust Coeff.**	**Ground Reflectivity**
(--)	**(--)**	**(…)**	**(*F)**	**(*F)**	**(%)**	**(mph)**	**(*F)**	**(j/m2/s/C)**	**(%)**	**(--)**	**(%)**
	conditions										
BH26	channel geometry changed to reference conditions	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14
BH28	existing conditions modeled	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14
BH28	vegetation changed to reference conditions	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14

Table C-13. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		Date	Optional Shading Variables										
Model Reach	Model Description	Month/ Day	Segment Azimuth	Topo. Altitude (E)	Vegetation Height (E)	Vegetation Crown (E)	Vegetation Offset (E)	Vegetation Density (E)	Topo. Altitude (W)	Vegetation Height (W)	Vegetation Crown (W)	Vegetation Offset (W)	Vegetation Density (W)
(--)	(--)	(--)	(degrees)	(degrees)	(ft)	(ft)	(ft)	(%)	(degrees)	(ft)	(ft)	(ft)	(%)
BH18	existing conditions modeled	15-Jul	-6.6	3	12	6	8	46.22%	3	13	6	12	73.12 %
BH22	existing conditions modeled	15-Jul	-0.8	3	9	4	10	26.99%	3	4	2	1	4.39%
BH22	vegetation changed to reference conditions	15-Jul	-0.8	3	12	6	8	46.22%	3	13	6	12	73.12 %
BH22	channel geometry changed to reference conditions	15-Jul	-0.8	3	9	4	10	26.99%	3	4	2	1	4.39%
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	-0.8	3	12	6	8	46.22%	3	13	6	12	73.12 %
BH26	existing conditions modeled	15-Jul	5.2	1.5	6	2	20	7.80%	4	3	2	1	6.33%
BH26	vegetation changed to reference conditions	15-Jul	5.2	1.5	12	6	8	46.22%	4	13	6	12	73.12 %

Table C-13. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		Date	Optional Shading Variables										
Model Reach	Model Description	Month/ Day	Segment Azimuth	Topo. Altitude (E)	Vegetation Height (E)	Vegetation Crown (E)	Vegetation Offset (E)	Vegetation Density (E)	Topo. Altitude (W)	Vegetation Height (W)	Vegetation Crown (W)	Vegetation Offset (W)	Vegetation Density (W)
(--)	(--)	(--)	(degrees)	(degrees)	(ft)	(ft)	(ft)	(%)	(degrees)	(ft)	(ft)	(ft)	(%)
BH26	channel geometry changed to reference conditions	15-Jul	5.2	1.5	6	2	20	7.80%	4	3	2	1	6.33%
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	5.2	1.5	12	6	8	46.22%	4	13	6	12	73.12 %
BH28	existing conditions modeled	15-Jul	11.6	2	2.5	1	0	45.10%	5	8	2	2	60.85 %
BH28	vegetation changed to reference conditions	15-Jul	11.6	2	12	6	8	46.22%	5	13	6	12	73.12 %

Table C-14. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Model Results - Outflow Temperature**					
Model Reach	**Model Description**	**Month/ Day**	**Predicted Mean**	**Mean TOut - Mean TIn**	**Length Normalized Mean TOut - Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**	**(*F)**	**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 10 cfs					
BH18	existing conditions modeled	15-Jul	66.30	0.10	0.08	81.12	14.82	11.36
BH22	existing conditions modeled	15-Jul	68.34	2.14	0.35	83.95	15.61	2.56
BH22	vegetation changed to reference conditions	15-Jul	66.95	0.75	0.12	82.10	15.15	2.49
BH22	channel geometry changed to reference conditions	15-Jul	68.07	1.87	0.31	82.99	14.92	2.45
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	66.35	0.15	0.02	80.51	14.16	2.33
BH26	existing conditions modeled	15-Jul	67.98	1.78	0.68	83.91	15.93	6.10
BH26	vegetation changed to reference conditions	15-Jul	66.77	0.57	0.22	81.96	15.19	5.82
BH26	channel geometry changed to reference conditions	15-Jul	67.54	1.34	0.51	82.69	15.15	5.80
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	66.24	0.04	0.02	80.12	13.88	5.32
BH28	existing conditions modeled	15-Jul	66.33	0.13	0.24	81.53	15.20	28.46
BH28	vegetation changed to reference conditions	15-Jul	66.24	0.04	0.07	80.97	14.73	27.58

Table C-15. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Model Results-Outflow Temperature**					
Model Reach	**Model Description**	**Month/ Day**	**Predicted Mean**	**Mean TOut -Mean TIn**	**Length Normalized Mean TOut -Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**	**(*F)**	**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 20 cfs					
BH18	existing conditions modeled	15-Jul	66.33	0.13	0.10	80.07	13.74	10.53
BH22	existing conditions modeled	15-Jul	68.10	1.90	0.31	82.80	14.70	2.41
BH22	vegetation changed to reference conditions	15-Jul	67.01	0.81	0.13	81.18	14.17	2.33
BH22	channel geometry changed to reference conditions	15-Jul	67.72	1.52	0.25	81.34	13.62	2.24
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	66.49	0.29	0.05	79.27	12.78	2.10
BH26	existing conditions modeled	15-Jul	67.50	1.30	0.50	82.54	15.04	5.76
BH26	vegetation changed to reference conditions	15-Jul	66.72	0.52	0.20	80.94	14.22	5.45
BH26	channel geometry changed to reference conditions	15-Jul	67.11	0.91	0.35	80.81	13.70	5.25
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	66.32	0.12	0.05	78.76	12.44	4.77
BH28	existing conditions modeled	15-Jul	66.30	0.10	0.19	80.35	14.05	26.31
BH28	vegetation changed to reference conditions	15-Jul	66.25	0.05	0.09	79.88	13.63	25.52

Table C-16. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Model Results-Outflow Temperature**					
Model Reach	**Model Description**	**Month /Day**	**Predicted Mean**	**Mean TOut - Mean TIn**	**Length Normalized Mean TOut -Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**	**(*F)**	**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 30 cfs					
BH18	existing conditions modeled	15-Jul	66.33	0.13	0.10	79.21	12.88	9.87
BH22	existing conditions modeled	15-Jul	67.87	1.67	0.27	81.81	13.94	2.29
BH22	vegetation changed to reference conditions	15-Jul	66.99	0.79	0.13	80.38	13.39	2.20
BH22	channel geometry changed to reference conditions	15-Jul	67.49	1.29	0.21	80.14	12.65	2.08
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	66.53	0.33	0.05	78.35	11.82	1.94
BH26	existing conditions modeled	15-Jul	67.25	1.05	0.40	81.45	14.20	5.44
BH26	vegetation changed to reference conditions	15-Jul	66.66	0.46	0.18	80.07	13.41	5.14
BH26	channel geometry changed to reference conditions	15-Jul	66.91	0.71	0.27	79.53	12.62	4.84
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	66.34	0.14	0.05	77.79	11.45	4.39
BH28	existing conditions modeled	15-Jul	66.29	0.09	0.17	79.43	13.14	24.61
BH28	vegetation changed to reference conditions	15-Jul	66.25	0.05	0.09	79.01	12.76	23.90

Table C-17. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Model Results-Outflow Temperature**					
Model Reach	**Model Description**		**Predicted Mean**	**Mean TOut - Mean TIn**	**Length Normalized Mean TOut -Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**		**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 40 cfs					
BH18	existing conditions modeled		66.32	0.12	0.09	78.52	12.20	9.35
BH22	existing conditions modeled		67.70	1.50	0.25	80.99	13.29	2.18
BH22	vegetation changed to reference conditions		66.96	0.76	0.12	79.69	12.73	2.09
BH22	channel geometry changed to reference conditions		67.32	1.12	0.18	79.21	11.89	1.95
BH22	vegetation & channel geometry changed to reference conditions		66.54	0.34	0.06	77.62	11.08	1.82
BH26	existing conditions modeled		67.08	0.88	0.34	80.59	13.51	5.18
BH26	vegetation changed to reference conditions		66.62	0.42	0.16	79.36	12.74	4.88
BH26	channel geometry changed to reference conditions		66.79	0.59	0.23	78.59	11.80	4.52
BH26	vegetation & channel geometry changed to reference conditions		66.34	0.14	0.05	77.05	10.71	4.10
BH28	existing conditions modeled		66.28	0.08	0.15	78.70	12.42	23.26
BH28	vegetation changed to reference conditions		66.25	0.05	0.09	78.31	12.06	22.58

Table C-18. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Model Results-Outflow Temperature**					
Model Reach	**Model Description**	**Mont h/Day**	**Predicted Mean**	**Mean TOut -Mean TIn**	**Length Normalized Mean TOut -Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**		**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 50 cfs					
BH18	existing conditions modeled	15-Jul	66.32	0.12	0.09	77.95	11.63	8.91
BH22	existing conditions modeled	15-Jul	67.56	1.36	0.22	80.30	12.74	2.09
BH22	vegetation changed to reference conditions	15-Jul	66.92	0.72	0.12	79.11	12.19	2.00
BH22	channel geometry changed to reference conditions	15-Jul	67.21	1.01	0.17	78.48	11.27	1.85
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	66.54	0.34	0.06	77.04	10.50	1.72
BH26	existing conditions modeled	15-Jul	66.97	0.77	0.30	79.89	12.92	4.95
BH26	vegetation changed to reference conditions	15-Jul	66.58	0.38	0.15	78.77	12.19	4.67
BH26	channel geometry changed to reference conditions	15-Jul	66.71	0.51	0.20	77.85	11.14	4.27
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	66.34	0.14	0.05	76.46	10.12	3.88
BH28	existing conditions modeled	15-Jul	66.27	0.07	0.13	78.10	11.83	22.15
BH28	vegetation changed to reference conditions	15-Jul	66.25	0.05	0.09	77.74	11.49	21.52

Table C-19. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Model Results-Outflow Temperature**					
Model Reach	**Model Description**	**Month/ Day**	**Predicted Mean**	**Mean TOut - Mean TIn**	**Length Normalized Mean TOut - Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**		**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 60 cfs					
BH18	existing conditions modeled	15-Jul	66.32	0.12	0.09	77.47	11.15	8.54
BH22	existing conditions modeled	15-Jul	67.45	1.25	0.21	79.71	12.26	2.01
BH22	vegetation changed to reference conditions	15-Jul	66.89	0.69	0.11	78.61	11.72	1.92
BH22	channel geometry changed to reference conditions	15-Jul	67.11	0.91	0.15	77.87	10.76	1.77
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	66.54	0.34	0.06	76.55	10.01	1.64
BH26	existing conditions modeled	15-Jul	66.89	0.69	0.26	79.29	12.40	4.75
BH26	vegetation changed to reference conditions	15-Jul	66.56	0.36	0.14	78.26	11.70	4.48
BH26	channel geometry changed to reference conditions	15-Jul	66.66	0.46	0.18	77.25	10.59	4.06
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	66.34	0.14	0.05	75.98	9.64	3.69
BH28	existing conditions modeled	15-Jul	66.26	0.06	0.11	77.60	11.34	21.24
BH28	vegetation changed to reference conditions	15-Jul	66.24	0.04	0.07	77.25	11.01	20.62

Table C-20. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Model Results-Outflow Temperature**					
Model Reach	**Model Description**	**Month/Day**	**Predicted Mean**	**Mean TOut -Mean TIn**	**Length Normalized Mean TOut -Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**		**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 70 cfs					
BH18	existing conditions modeled	15-Jul	66.31	0.11	0.08	77.06	10.75	8.24
BH22	existing conditions modeled	15-Jul	67.36	1.16	0.19	79.20	11.84	1.94
BH22	vegetation changed to reference conditions	15-Jul	66.85	0.65	0.11	78.17	11.32	1.86
BH22	channel geometry changed to reference conditions	15-Jul	67.04	0.84	0.14	77.36	10.32	1.69
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	66.53	0.33	0.05	76.13	9.60	1.58
BH26	existing conditions modeled	15-Jul	66.82	0.62	0.24	78.79	11.97	4.59
BH26	vegetation changed to reference conditions	15-Jul	66.53	0.33	0.13	77.82	11.29	4.33
BH26	channel geometry changed to reference conditions	15-Jul	66.61	0.41	0.16	76.74	10.13	3.88
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	66.34	0.14	0.05	75.56	9.22	3.53
BH28	existing conditions modeled	15-Jul	66.26	0.06	0.11	77.17	10.91	20.43
BH28	vegetation changed to reference conditions	15-Jul	66.24	0.04	0.07	76.84	10.60	19.85

Table C-21. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		Date	Model Results-Outflow Temperature					
Model Reach	**Model Description**	**Month/Day**	**Predicted Mean**	**Mean TOut -Mean TIn**	**Length Normalized Mean TOut -Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**		**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 80 cfs					
BH18	existing conditions modeled	15-Jul	66.31	0.11	0.08	76.70	10.39	7.96
BH22	existing conditions modeled	15-Jul	67.28	1.08	0.18	78.76	11.48	1.89
BH22	vegetation changed to reference conditions	15-Jul	66.83	0.63	0.10	77.79	10.96	1.80
BH22	channel geometry changed to reference conditions	15-Jul	66.98	0.78	0.13	76.92	9.94	1.63
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	66.52	0.32	0.05	75.77	9.25	1.52
BH26	existing conditions modeled	15-Jul	66.77	0.57	0.22	78.34	11.57	4.43
BH26	vegetation changed to reference conditions	15-Jul	66.51	0.31	0.12	77.44	10.93	4.19
BH26	channel geometry changed to reference conditions	15-Jul	66.58	0.38	0.15	76.32	9.74	3.73
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	66.33	0.13	0.05	75.21	8.88	3.40
BH28	existing conditions modeled	15-Jul	66.26	0.06	0.11	76.79	10.53	19.72
BH28	vegetation changed to reference conditions	15-Jul	66.24	0.04	0.07	76.48	10.24	19.18

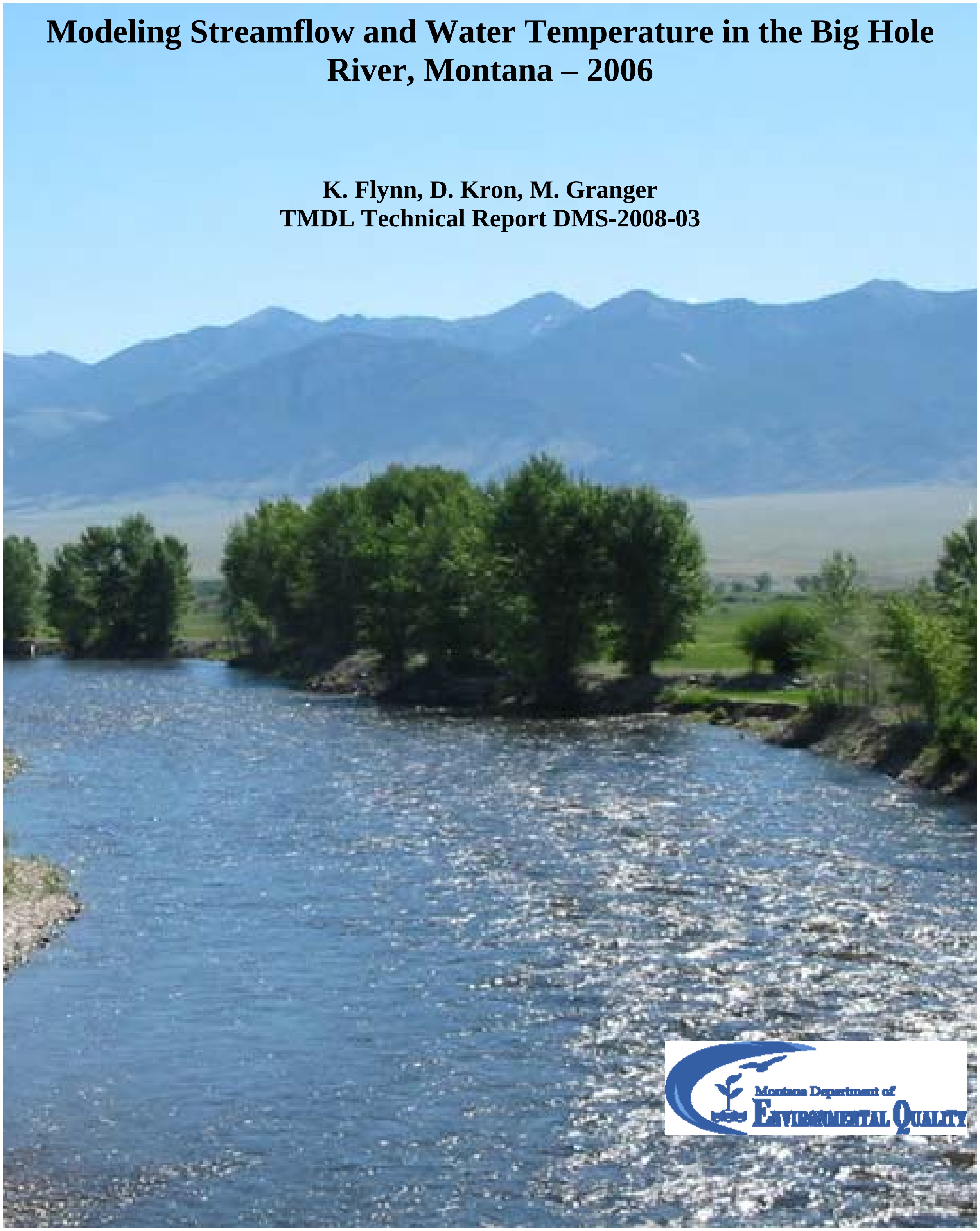
Table C-22. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Model Results-Outflow Temperature**					
Model Reach	**Model Description**	**Month /Day**	**Predicted Mean**	**Mean TOut -Mean TIn**	**Length Normalized Mean TOut -Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**		**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 90 cfs					
BH18	existing conditions modeled	15-Jul	66.31	0.11	0.08	76.38	10.07	7.72
BH22	existing conditions modeled	15-Jul	67.21	1.01	0.17	78.36	11.15	1.83
BH22	vegetation changed to reference conditions	15-Jul	66.80	0.60	0.10	77.44	10.64	1.75
BH22	channel geometry changed to reference conditions	15-Jul	66.93	0.73	0.12	76.53	9.60	1.58
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	66.52	0.32	0.05	75.45	8.93	1.47
BH26	existing conditions modeled	15-Jul	66.73	0.53	0.20	77.95	11.22	4.30
BH26	vegetation changed to reference conditions	15-Jul	66.50	0.30	0.11	77.09	10.59	4.06
BH26	channel geometry changed to reference conditions	15-Jul	66.55	0.35	0.13	75.94	9.39	3.60
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	66.33	0.13	0.05	74.90	8.57	3.28
BH28	existing conditions modeled	15-Jul	66.25	0.05	0.09	76.46	10.21	19.12
BH28	vegetation changed to reference conditions	15-Jul	66.24	0.04	0.07	76.16	9.92	18.58

Table C-23. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Model Results-Outflow Temperature**					
Model Reach	**Model Description**	**Month /Day**	**Predicted Mean**	**Mean TOut - Mean TIn**	**Length Normalized Mean TOut - Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**		**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 100 cfs					
BH18	existing conditions modeled	15-Jul	66.30	0.10	0.08	76.09	9.79	7.50
BH22	existing conditions modeled	15-Jul	67.16	0.96	0.16	78.00	10.84	1.78
BH22	vegetation changed to reference conditions	15-Jul	66.78	0.58	0.10	77.13	10.35	1.70
BH22	channel geometry changed to reference conditions	15-Jul	66.89	0.69	0.11	76.19	9.30	1.53
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	66.51	0.31	0.05	75.17	8.66	1.42
BH26	existing conditions modeled	15-Jul	66.69	0.49	0.19	77.60	10.91	4.18
BH26	vegetation changed to reference conditions	15-Jul	66.48	0.28	0.11	76.79	10.31	3.95
BH26	channel geometry changed to reference conditions	15-Jul	66.53	0.33	0.13	75.61	9.08	3.48
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	66.33	0.13	0.05	74.62	8.29	3.18
BH28	existing conditions modeled	15-Jul	66.25	0.05	0.09	76.16	9.91	18.56
BH28	vegetation changed to reference conditions	15-Jul	66.24	0.04	0.07	75.87	9.63	18.03

APPENDIX D
MODELING STREAMFLOW AND WATER TEMPERATURE IN THE BIG HOLE RIVER, MONTANA - 2006



Front Cover: Big Hole River above the confluence with the Jefferson River

Image courtesy of: Big Sky Fishing.Com; http://www.bigskyfishing.com

Other Credits:

Outreach and landowner coordination: Big Hole River Watershed Committee
Field data collection: Watershed Consulting, Inc.

EXECUTIVE SUMMARY

The one-dimensional, dynamic water quality model Heatsource v7.0 was applied to the Big Hole River in southwestern Montana to evaluate stream temperature improvement scenarios for a 152.5 kilometer reach extending from approximately Wisdom to the confluence with the Beaverhead River near Twin Bridges. This reach has been identified as a primary concern due to elevated summer temperatures, low late-season flows, and the presence of Arctic grayling. An extensive field investigation was completed during summer 2006 to support the modeling. This included measurement of streamflow and water temperature at 20 Big Hole River main-stem locations, 44 tributaries and irrigation return flows, and 33 irrigation withdrawls.

Characterization of river hydraulics, measurement of stream shade, and continuous monitoring of climate were also completed. Results of predictive modeling suggest that the Big Hole River is impaired due to management activities, and that decreases of 0.13 and 0.59ºC (0.23 and 1.06ºF) in average and maximum temperatures could be achieved per implementation of "all reasonable soil and water conservation practices" (ARM 17.30.602). Temperatures would be 0.69 and 2.76ºC (1.24 and 4.97ºF) cooler under natural conditions. Through analysis of shade, geomorphology, and in-stream flow conditions, it was shown that flow alteration is the most significant contributor to warming of river, and subsequently, the most feasible alternative for returning the Big Hole to a more natural thermal regime. This of course, would require decreases in consumptive use either through irrigation efficiency improvements, or decreases in domestic water withdrawl. Finally, a unique condition was identified near the center of the watershed where significant groundwater influx and topographic shading result in thermal "resetting" of in-stream water temperatures. This functionally separates the upper and lower Big Hole River TMDL planning areas, and will allow for future management of the river as two distinct segments. This work has been initiated by Montana by Montana Department of Environmental Quality as part of the Total Maximum Daily Load (TMDL) program.

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Conversion Factors and Datum

1 meter = 3.2808 feet
1 cubic meter per second (cms) = 35.313 cubic feet per second (cfs)
1 kilometer = 0.622 miles
1 square kilometer = 0.386 square miles

ACRONYMS

7Davg	7-day mean temperature
7Dmax	7-day maximum temperature
7Dmin	7-day minimum temperature
7Q5	7-day 5-year low flow
ARM	Administrative Rules of Montana
BHWC	Big Hole River Watershed Committee
BLM	Bureau of Land Management
BMPs	Best Management Practices
ºC	Degrees Celsius
COOP	Cooperative Observer
CWA	Clean Water Act
cfs	cubic feet per second
cms	cubic meters per second
CWAIC	Clean Water Act Information Center
DEM	Digital Elevation Model
DEQ	Montana Department of Environmental Quality
EPA	Environmental Protection Agency
ESA	Endangered Species Act
ET	Evapotranspiration
ºF	Degrees Fahrenheit
FWP	Montana Fish, Wildlife, and Parks
FY	Fiscal Year
GIS	Geographic Information System
HUC	Hydrologic Unit Code
LULC	Land Use/Land Cover
LSWCP	Land, Soil, and Water Conservation Practices
NAD83	National Accumulation of Datum - 1983
NAIP	National Agricultural Imagery Program
NAVD88	National Accumulation of Vertical Datum - 1988
NED	National Elevation Dataset
NHD	National Hydrography Dataset
NIST	National Institute of Standards and Technology
NLDC	National Land Cover Dataset
NOAA	National Oceanic and Atmospheric Administration
NPS	Nonpoint Source
NRCS	Natural Resources Conservation Service
NSE	Nash-Sutcliffe Coefficient of Efficiency
PBIAS	Percent Bias
QA	Quality Assurance
RAWS	Remote Automated Weather Station
SSR	Sum of Squared Residuals
SSTEMP	Stream Segment Temperature Model
TMDL	Total Maximum Daily Load
Tavg	Mean daily water temperature

Tmax	Maximum daily water temperature
Tmin	Minimum daily water temperature
TPA	TMDL Planning Area
UILT	Upper incipient lethal limit
USFWS	U.S. Fish and Wildlife Service
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
WRCC	Western Regional Climate Center
WRS	Water Resource Surveys

BACKGROUND

Conflicting demands between irrigated agriculture, anglers, and aquatic species have long been an issue in the arid west (Thomas and Anderson, 1976; Anderson, 1982; Pimentel et al, 1997; Pringle, 2000). The Big Hole River in southwestern Montana is no different, and mounting evidence suggests that low flow conditions and extensive dewatering have elevated summer water temperatures such that beneficial uses of the water body are impaired (CWAIC, 2006). As a result, Montana Department of Environmental Quality (DEQ) has commissioned a water temperature study such that the mechanistic relationship between in-stream water temperature, stream morphology, riparian conditions, and associated water management practices can be established for the summer critical low-flow period. Specifically, the one-dimensional, dynamic stream water quality model Heatsource v7.0 (Boyd and Kasper, 2004) was applied to a 152.5 kilometer reach extending from approximately Wisdom to the confluence with the Beaverhead River near Twin Bridges to evaluate irrigation improvement efficiencies and associated scenarios as part of the Total Maximum Daily Load (TMDL) program. This reach has been identified as a primary concern due to elevated summer temperatures, low late-season flows, and the presence of the last remaining native population of river-dwelling Arctic grayling in the lower 48 states (Magee et al., 2006; Rens and Magee, 2007). Subsequent analysis was also completed for a 94.5-km reach upstream of the project site using SSTEMP (Barthalow, 1989) to evaluate potential changes in headwater boundary conditions from upstream management activities.

Prior Studies

The Big Hole River has long been a concern in regard to elevated water temperatures and aquatic species. Lohr et al. (1996) documented fish kills in July of 1994 as water temperatures reached the upper incipient lethal limit (UILT) for Arctic Grayling of 25ºC (77ºF). Again, in 2002 and 2003, Magee and Lamothe (2003, 2004) recorded in-stream temperatures well above the UILT. Maximum values those years exceeded 27ºC (80.8ºF) and 26ºC (80.1ºF) respectively. The temporal duration of these impairments has been well characterized. According to the Big Hole River Watershed Committee (2000), threshold daily water temperature near the center of the watershed (e.g. the USGS gage near Melrose) has exceeded the indicator target of 21.1ºC (70ºF) at least once every year since 1977 while the 7-day average daily maximum temperature [7Dmax; e.g. 20ºC (68ºF)] has been exceeded 19 out of 22 years. Temperatures have been shown to be elevated in the lower reaches as well, with large longitudinal gradients extending as far downstream as Twin Bridges (Gammons et al., 2001). Significant surface water withdrawl has been cited as the greatest threat to the fishery (FWP 1989). As such, Montana Fish, Wildlife, and Parks (FWP) has characterized the river as chronically dewatered from approximately Glen to the confluence with the Jefferson River, and periodically throughout much of the rest of the watershed (MFISH 2007). Persistent drought has exacerbated effects of water use such that FWP has requested several year-round flow reservations to minimize the extent of withdrawl during the critical flow period (Rens and Magee, 2007). In addition to these preventative measures, the Big Hole River Drought Management Plan has been drafted to address voluntary water conservation and fishing closures in the basin. Currently, there are three triggers that result in fishing closures on the river (BHWC 2000): (1) when river temperatures exceed 21.1ºC (70ºF) for over 8 hours per day for three consecutive days, (2) when flows fall below 2.8 cms (100 cfs) at the USGS Mudd Creek gage, or (3) when flows are less than 7.1 cms (250 cfs) at the Melrose gage. In addition to these efforts, ongoing conservation projects have been implemented to improve streamflow, protect the function of streams and riparian habitats, and identify and eliminate threats to grayling (Rens and Magee, 2007). Thus, some action has already been taken to mitigate the symptoms of the temperature impairment in the basin. However, DEQ wishes to evaluate river corridor management scenarios such that cumulative effects of these activities on in-stream temperature can be identified. The goal of this study is to identify whether a suite of best management practices (BMPs) can be implemented in the river corridor such that the Montana steam temperature standard is attained and maintained (ARM 17.30.623).

Montana Temperature Standard (ARM 17.30.623)

Montana's in-stream temperature standard was originally developed to address point source discharges and therefore is difficult to interpret for non-point sources without use of water quality models. This is especially true when attempting to characterize departure from "natural occurring" conditions which effectively reflects the implementation of "all reasonable soil and water conservation practices" (ARM 17.30.602). As currently written, a maximum allowable increase of 0.55ºC (1ºF) over "naturally occurring" is acceptable for B-1 waters when natural temperatures are within the range of 0ºC to 18.9 ºC (32ºF to 66ºF). For temperatures 19.2 ºC (66.5ºF) or greater, a 0.23ºC (0.5ºF) increase is allowed (ARM 17.30.623 (2)(e)). Monitoring and modeling has been structured such that the existing temperature regime can be adequately addressed along with the expected temperatures from implementation of BMP improvements.

STUDY AREA

The Big Hole River drains approximately 7,250-km2 (2,800-mi2) of high- and mid-elevation mountainous topography in southwestern Montana. Originating from the continental divide, the river flows 247-km past the towns of Jackson, Wisdom, Wise River, Melrose, and Glen before reaching its endpoint near Twin Bridges. The entire watershed is part of United States Geological Survey (USGS) Hydrologic Unit Code (HUC) 10020004 and consists of predominantly of wide alluvial valleys that are constrained at a number of locations by narrowing geological outcrops. Currently, 242.5 km (150.7 miles) of the mainstem are listed as impaired for thermal modification (CWAIC, 2006). Given the size of the watershed, the study area has been broken into three distinct planning segments: (1) the upper TMDL planning area (TPA) which extends from the headwaters to Pintlar Creek, (2) middle TPA which extends from Pintlar Creek to Divide Creek (near Wisdom and Melrose respectively), and (3) the lower TPA which extends from Divide Creek to the confluence with the Beaverhead River. The DEQ study is focused primarily on the lower two TPA's extending from Pintlar Creek to the confluence with the Beaverhead River. The project site is most easily accessed via I-15 between Butte and Dillon, Highway-141 between Melrose and Wisdom, and on Burma Road between Glen and Twin Bridges (**fig D-1**).

Climate

Climate in the Big Hole River watershed is inter-montane continental, with marked seasonality (**fig. D-2a**). Cooperative observation station Divide 2 NW (COOP ID 242421) indicates that average temperatures during 1971-2000 range from 25 to 30°C in the summer months to as low as -10°C in the winter (WRCC, 2007). July and August are the warmest months of the year, and are influenced by Pacific high pressure systems that cause long periods of warm and dry weather. Clear skies and warm days prevail during these months. Because of the high elevation of the watershed, the diurnal variation in temperature is often greater that other areas of Montana, characteristic of warm days and cool nights (Deer Lodge WRS, 1955). Average precipitation in the watershed ranges from 250-300 mm (10-12 inches) in the valleys to over 1,000 mm (50 inches) in the mountains (Marvin and Voller, 2000). Most of this precipitation occurs during the spring and winter months.

Surface Water

Watershed hydrology is predominately snowmelt driven and there are three operational USGS gaging stations in the study area. These include: (1) USGS 06016000 Big Hole River below Mudd Creek, (2) USGS 06017000 Big Hole River nr Melrose, and (3) USGS 06018500 Big Hole River nr Glen. Additionally, a fourth gage exists upstream of the project site, USGS 06024450 Big Hole River below Big Lake Creek at Wisdom, MT. Mean monthly streamflow for the period of record for the four sites (1997-2006) is shown in fig. 2b. Typically, spring snowmelt begins in mid to late March, peaks in June, and then rapidly declines in July and August toward baseflow. Minimum discharges usually occur during late summer months and often result in late-season shortages of irrigation water (Marvin and Voller, 2000). Tributary inflow to the Big Hole River is highly variable, and depends largely on drainage area and basin elevation. The largest tributary to the Big Hole River is Wise River, which contributes mean annual discharge of 3.9 cms (138 cfs). Other important tributaries in the study reach include Fishtrap Creek, LaMarche Creek, Deep Creek, Divide Creek, and Willow Creek..

Groundwater

According to Marvin and Voeller (2000), tertiary and quaternary sediment deposits are the most important hydrogeologic features of the Big Hole River. These stratigraphic layers form the extensive groundwater system that immediately underlies the Big Hole River. Both Marvin et al., (1997) and Marvin and Voeller (2000) provide detailed information on groundwater resources in the basin. From review of their work, seasonal groundwater head fluctuations occur in excess of 1.5-4.5 m (5-15 feet) during the irrigation season as a result of percolation losses from irrigated pastures and irrigation canals. Losses, combined with spring rain and snowmelt, contribute to substantial gains in aquifer storage during May and June. In late summer (e.g. July and August), infiltrating water is thought to be consumed by evapotranspiration (ET) rather than being returned to surface water. Finally, at the onset of plant dormancy, return flow again becomes a significant component of the water balance and streamflow gains of 2.5 cms (90 cfs) are reported. During the period of 1997-2006, a gain of 3.25 cms (115 cfs) was observed (fig. 2b).

Groundwater-Surface water

Several groundwater-surface water interaction studies have been completed in the Big Hole Watershed in recent years. Levings (1986) noted that flood irrigation in the upper watershed was a significant contributor of recharge to the near surface aquifer. Marvin (1997) quantified the extent of surface water losses and found that 0.027 cms per km (0.6 cfs per mile) was lost from irrigation ditches to groundwater. Further work completed by Marvin and Voller (2000) confirmed that irrigation losses in the basin were significant. They documented gains in groundwater storage and associated return flows during the spring and fall months. In the summer, much of this water is consumed by ET rather than being discharged back to the river through return flow and/or shallow groundwater accretion.

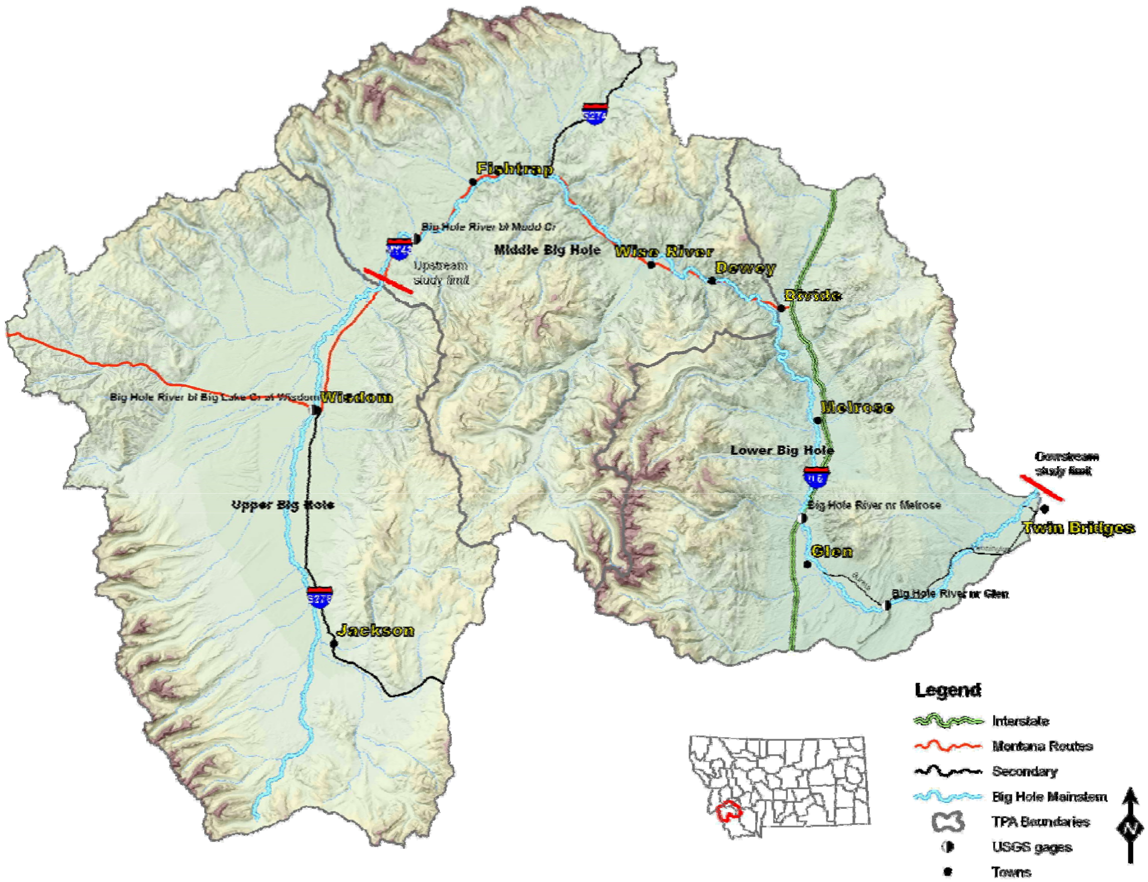
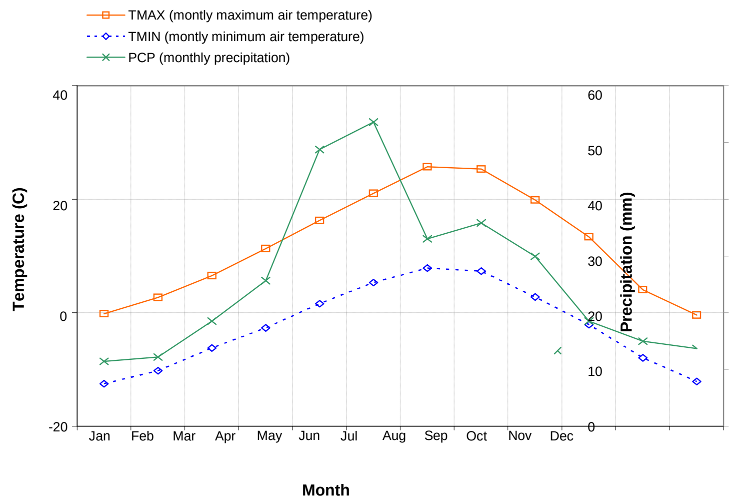
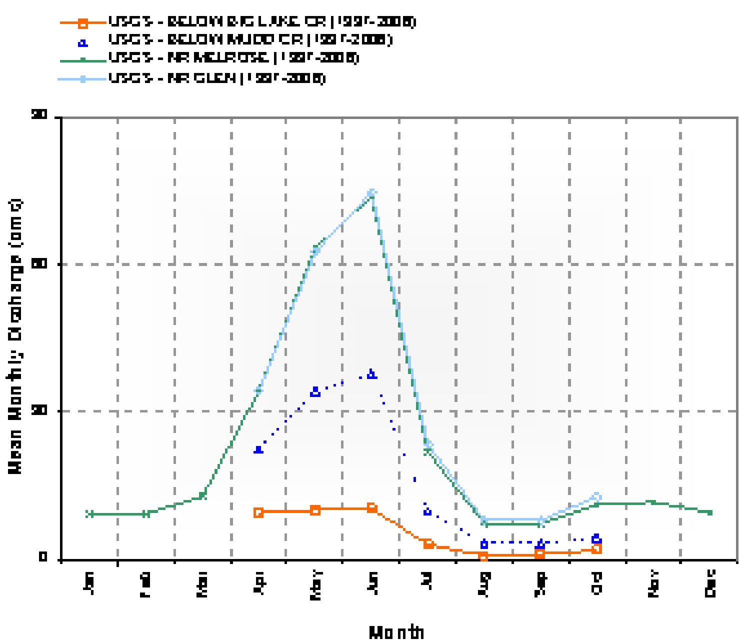


Figure D-1. Big Hole River watershed, hydrography, and stream-flow gaging stations. The modeling reach extends from downstream of Wisdom to the watershed outlet near Twin Bridges, MT. The limits of the project reach are delineated in red.



a)



b)

Figure D-2. Big Hole River climate at Divide 2 NW (1971-2000); b) USGS hydrology.

Irrigation & Domestic Use

Alfalfa and grass hay production are the primary agricultural practices in the Big Hole River watershed that require irrigation. Two cuttings of hay occur in the lower basin while the upper basin is limited to one due to climate. Irrigation water is typically distributed through unlined ditches and canals, with field application by either flooding or sprinkler (Marvin and Voller, 2000). Irrigation is reported heaviest downstream of Melrose. According to Wells and Decker-Hess (1981), withdrawals in the lower Big Hole between Melrose and Twin Bridges have ranged from between 2.27 to 5.95 cms (80-210 cfs), with up to 9.29 cms (328 cfs) being removed from the river during the summer of 1980. Bahls (1978) qualitatively supports this assertion reporting 44 diversions between Divide Creek and the mouth. While irrigation in the upper Big Hole is less documented, it is still significant. In 2004 a total of 15 ranchers were paid to stop irrigating approximately 5,500 ha (13,685 acres) in the upper basin with financial assistance from the Natural Resources Conservation Service (NRCS). Prior to implementation, the river was dewatered to 0.85 cms (30 cfs). Days after shutoff streamflow rose significantly (MRA, 2007). Note: DEQ's review of this event indicates the response was likely biased from rains and associated runoff response.

Domestic water use in the Big Hole is somewhat limited. The primary user is the Butte-Silver Bow Water Utility. During July 2006, average pumping from the Feeley Plant near Divide was 0.38 cms (13.4 cfs).

METHODS AND MATERIALS

An intensive field data collection effort was completed during the summer of 2006 to characterize continuous water temperature, meteorological forcings (e.g. air temperature, relative humidity, wind speed, etc.), and the associated water balance in support of the modeling effort. The intensive one-week synoptic monitoring program was supplemented with information from the USGS National Water Information Program, National Oceanic and Atmospheric Administration (NOAA) Cooperative Observer program (COOP), Remote Automated Weather Station (RAWS) program, and Bureau of Reclamation AGRIMET network to provide comprehensive data regarding the project reach.

Site Selection

Sites for discharge and temperature monitoring were identified by DEQ as part of the original project scoping (DEQ/Watershed Consulting, 2006). In total, 20 main-stem locations, 44 tributaries and irrigation return flows, and 33 irrigation withdrawals were monitored in the field. Sites were accessed primarily by watercraft, as project teams floated through the study reach to characterize water exchanges and associated temperatures for modeling. Irrigation diversions were identified using Montana Water Resource Surveys (WRS) for Deer Lodge (1955), Madison (1965), and Silver Bow Counties (1955). Since no survey was published for Beaverhead County, these points were identified in the field by GPS, and then were later correlated with information from the Lower Big Hole River Irrigation Study currently in progress by PBS&J (J. Dunn, personal communication, February 2008).

Temperature Data

Continuous temperature data loggers were used to record diurnal variations in temperature as outlined in Barthalow (1989). Temperature dataloggers used in the Big Hole River modeling study were Optic StowAway® model number WTA32-05+37. The StowAway® is a completely sealed underwater temperature logger with capability to record continuous readings from 0.5 seconds to 9 hours. Temperature measurements were made at 15-minute increments, and were read on the hour for model input/calibration purposes. Logger calibration checks were completed both pre- and post deployment, and were within the acceptable range specified by DEQ (2007). Loggers have a NIST traceable temperature accuracy of ±0.2°C, therefore the absolute accuracy is 0.4ºC. Loggers were in the field for approximately one month.

Discharge Data

All major inflows and outflows were monitored over a one-week period to describe hydrologic flux in the watershed. Flow measurements were made using the current meter procedures discussed by Rantz (1982), or were estimated via the floating object procedure described by DEQ (1995). A combination of portable meters including a Marsh-McBirney Model 2000 Flo-Mate solid state meter, Price AA traditional meter, pygmy meter, and a propeller-based Swoffer meter were used. Relative precision of the measurements were addressed through meter tests at multiple depths within a single cross-section. Velocity variation was ±7.5 percent which is consistent with that of Harmel et al. (2000). Quality assurance (QA) checks also were made at discharge cross-section transects within ±5 percent.

Climate Data

Climate was field monitored so that measurements in the river corridor could be correlated with that of surrounding COOP, RAWS, and AGRIMET stations. Air temperature and wet bulb depression were measured with a U.S. Weather Bureau type sling phsychrometer having accuracy of ±0.5 °C. Wind speed was measured with a Dwyer hand-held wind meter (±0.2 m/s for low scales and ±1.3 m/s for high scales). Observations of cloud cover were also made to the nearest 10-percent. All measurements were completed four times daily.

Morphological and Shade Data

River morphology and riparian vegetation data were assessed in the field to characterize direct solar radiation losses from topography and vegetative shade. The following measurements were made to support the modeling: (1) bankfull and wetted channel width, (2) tree heights, (3) canopy density, (4) channel overhang, and (5) shade at specified transects. A fiberglass-tape, range-finder, clinometer, canopy densitometer, and solar pathfinder™ were used to acquire these attributes.

MODEL DEVELOPMENT

Model Description

Heatsource v7.0 is a dynamic continuous temperature model that operates on a sub hourly time-step (Boyd and Kasper, 2004). All components of the heat balance are simulated including incoming shortwave radiation, terrestrial longwave radiation, thermal conduction and convection, evaporative flux, and ground flux. Forcing functions required to simulate the heat flux across the air-water interface include air temperature, wind speed, relative humidity, and cloud cover. These interact with shade, river morphology, and adjacent tributaries to provide a comprehensive description of mass/heat transfer and advection/dispersion throughout the simulated system. Springs, tributaries, and return flows are assumed to be mixed instantaneously over the finite difference step in the model, and trapezoidal channel geometry and Manning's equation are used to estimate flow velocity and associated hydraulics for a given discharge and reach configuration. Evaporation is simulated using either a simplified mass transfer function, or a version the Penman method (Dingman, 2002). Dynamic water routing is completed by simultaneous solution of the St. Venant equations for continuity and momentum using either the Muskingum approximation or explicit finite difference method. Hyporheic flow is also simulated.

GIS Pre-processing

Heatsource v7.0 includes a spatially explicit ArcView3.2 GIS pre-processor called TTools for efficient calculation of morphologic and shading attributes at river scales (Boyd and Kaspar, 2004). Fundamental input data required for implementation of TTools includes: (1) site topography in the form of a digital elevation model (DEM), (2) digitized channel morphology (e.g. bankfull widths and centerline), (3) digitized riparian vegetation shapefile, and (4) user-defined vegetation characteristics. The 30-m USGS National Elevation Dataset (NED) was used for calculation of topographic characteristics. Channel centerline, bankfull geometry, and riparian vegetation classification were all digitized by DEQ using 2004 National Agricultural Imagery Program (NAIP) photography at a scale of 1:5,000. These were then converted to 1-m grid resolution for model pre-processing. Project coordinate system and datum were State-Plane NAD83 and NAVD88.

TTools includes a longitudinal and radial sampling algorithm that calculates site-specific morphologic and shading characteristics such as channel width and slope, topographic shade, and vegetative shade at user defined nodes (i and i+1) along the channel centerline (**fig. D-3**). A node distance of 100-m was used in the case of the Big Hole River and radial samples were completed at 15-m spacing to determine landcover attributes (e.g. tree height, density, channel overhang, etc.) for associated shading calculations. Additional information on TTools and Heatsource v7.0 setup are discussed in subsequent sections.

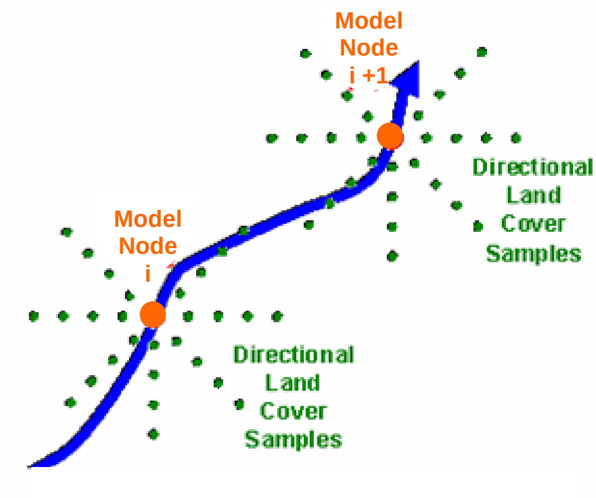


Figure D-3. Example of TTools radial sampling algorithm.

Simulation Period and Global Control Specifications

Following the initial pre-processing, the model simulation period was chosen to be consistent with the critical limiting period, i.e. where standards are most likely to be exceeded. Based on a review of water temperature data at USGS 06025500 Big Hole River nr Melrose MT (2000-2006) (**fig. D-4**), this period most frequently occurs in late July to early August, when air temperatures are the highest, and when photoperiod is sufficiently long. Thus the field data-collection was pre-scheduled to be coincident with this time period. Ultimately, the week of July 25-31, 2005 was used in the modeling. Other information specified during initial project planning were control information such as finite difference distances (dx) and time steps (dt)], evaporation approaches, and routing methodologies. Several combinations of dx/dt were evaluated as part of initial model testing including 500, 1,000, and 2,000-m distances and 5, 10, and 15 minute time increments. The combination of a 10-minute time-step and 1,000-m distance step was found to most readily balance model run time with computational rigor. The mass transfer evaporation approach (using Penman coefficients) and Muskingum channel routing were used as available data did not support use of more complex methodologies.

Hydrology/Mass Transfer Input

Hydrology and mass transfer data from the 2006 field effort were used to define the overall water balance and associated boundary conditions for the modeling (**table D-1**). Prior to the initiation of the project, flow conditions were evaluated in context with the historical gage record to determine their relative relationship with know low flow-frequency. As observed in **fig. D-4**, mean daily discharge at the USGS gage near Melrose for July 25-31, 2006 was approximately 4.2 cms (150 cfs). The mean daily statistic is nearer 17 cms (~600 cfs). This indicates that flows during 2006 were roughly equivalent to the 7-day, 5-year low flow condition (7Q5) (McCarthy, 2004); a duration and frequency that DEQ feels is appropriate for temperature study. Thus the model application was developed for the 7-day period of July 25-31, 2006; at, or near, the 7Q5. Locations of all hydrology/mass transfer monitoring sites are shown in **fig. D-5**. A more detailed map is in **Appendix-A**.

As seen in **fig. D-6a** and **b**, the hydrograph during the modeling period is clearly characteristic of unsteady flow conditions. Analysis of the 7-day period from July 25-31, 2006 indicates that a headwater change of nearly 50 percent occurred at the upstream end of the project reach (USGS gage near Wisdom). Subsequent downstream gages also exhibit similar effects. Given such large variation over a relative short time-period, it was decided that a dynamic upstream boundary condition was necessary to adequately reflect in-river flow conditions. Hourly data from the USGS Mudd Creek gage were used to distribute flow through time at this site. All other hydrology/mass transfer boundaries were considered steady-state, an assumption that was largely necessitated due to the fact that continuous flow monitoring of tributaries/irrigation exchanges was not feasible. Identified cross-correlation between USGS gages in the upper and lower reaches, further supports the steady-flow assumption.

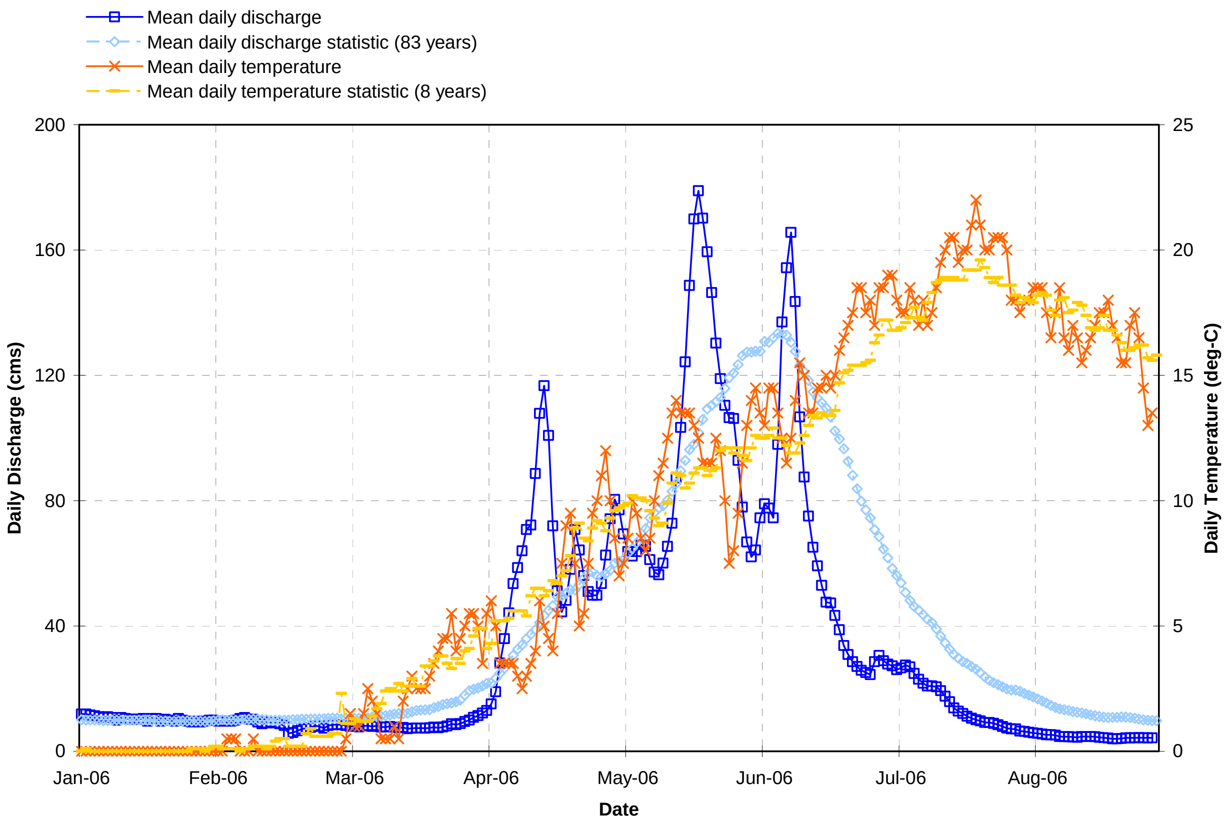


Figure D-4. Summary of mean daily discharge, temperature, and associated statistics for the USGS gage near Melrose, MT (USGS 06025500). Data from USGS National Water Information System (NWIS).

Table D-1. Instantaneous measured inflow, outflow, and associated water balance for the Big Hole River during the July 25-31, 2006 modeling period. All data are in cubic meters per second (m^3/s).

BIG HOLE RIVER WATER BALANCE 7/25-31/06	m^3/s	GWH_20 EST
Z01 - BIG HOLE RVR BELOW PINTLAR CR	**2.917**	
R02 - C-S WASTE RT	0.010	
R48 - BACON-NYHART RT	0.057	
R61 - SEEFIELD RT	0.028	0.064
R03 - MUDD CR	0.021	
R04 - SQAW CR	0.046	
TOTAL	**3.079**	**GAINING**
USGS 06016000 - BIG HOLE RVR @ MUDD CR	**3.143**	**3.143**
R52 - TOOMEY SPRING	0.012	
R54 - TOOMEY CR	0.014	0.824
TOTAL	**3.169**	**GAINING**
Z02 - BIG HOLE RVR 4.5 KM BELOW MUDD CR	**3.993**	**3.993**
T05 - SAWLOG CR	0.038	
R58 - STEWART CR	0.187	
R60 - PADDOCK/SOPER RT	0.020	0.080
R06 - FISHTRAP CR	0.779	
TOTAL	**5.017**	**GAINING**
Z03 - BIG HOLE RVR BELOW FISHTRAP FAS	**5.097**	**5.097**
R07 - LAMARCHE CR	0.575	0.077
TOTAL	**5.672**	**GAINING**
Z04 - BIG HOLE RVR BELOW SEYMOUR CR	**5.749**	**5.749**
R09 - BACON RTN	0.028	
R01 - SEYMOUR CR	0.116	
R05 - DEEP CR	0.767	-0.605
R08 - BRYANT CR	0.125	
A06 - BEAR CR	0.050	
TOTAL	**6.835**	**LOSING**
Z06 - BIG HOLE RVR ABOVE JOHNSON CR	**6.230**	**6.230**
R26 - JOHNSON CR	0.075	
A11 - ALDER CR	0.040	
R40 - UNNAMED DVT	-0.133	
R29 - MEADOW CR	0.170	-1.087
R31 - MEADOW CR RT	0.130	
TOTAL	**6.512**	**LOSING**
Z22 - BIG HOLE RVR ABOVE WISE RIVER	**5.425**	**5.425**
R71 - WISE RVR-1 (WEST)	1.463	
R32 - WISE RVR-2 (EAST)	0.595	0.076
TOTAL	**7.483**	**GAINING**
Z07 - BIG HOLE RVR ABOVE JERRY CR	**7.559**	**7.559**
R33 - JERRY CR	0.073	
I10 - SRING GULCH	0.087	2.897
TOTAL	**7.719**	**GAINING**
Z46 - BIG HOLE RVR NR POWERHOUSE FAS	**10.616**	**10.616**
O01 - BH PUMP ST. DVT	-0.439	
O08 - DIVIDE CANAL DVT	-0.700	
I11 - SHELTON-KAMBICH DVT	-0.255	
R39 - SHELTON-KAMBICH RT	0.023	-0.712
R10 - UNNAMED DVT	-0.084	
R38 - SHELTON-KAMBICH RT	0.028	
TOTAL	**9.189**	**LOSING**
Z21 - BIG HOLE RVR ABOVE DIVIDE CR	**8.477**	**8.477**
R16 - DIVIDE CR-1 (EAST)	0.102	
R20 - DIVIDE CR-2 (WEST)	0.085	1.052
I16 - UNNAMED TRIB (GOAT MTN)	0.079	
TOTAL	**8.743**	**GAINING**
Z08 - BIG HOLE RVR @ MAIDENROCK CANYON	**9.795**	**9.795**
R35 - CANYON CR	0.112	
I50 - MOOSE CR	0.238	
I17 - MCCAULY-1 DVT	-0.586	0.578
R12 - MERIWETHER DVT	-0.470	
TOTAL	**9.089**	**GAINING**
Z09 - BIG HOLE RVR NR MAIDENROCK FAS	**9.667**	**9.667**
Z09 - BIG HOLE RVR NR MAIDENROCK FAS	**9.667**	**9.667**
R34 - MCCAULY-2, MELROSE DVT	-0.484	
R15 - MERIWETHER RTN	0.189	
R36 - SOAP CR	0.064	
I20 - ROBBINS (MERIWETHER) DVT	-0.057	
O02 - BOWE (CARPENTER) DVT	-0.163	
R23 - CAMP CR	0.021	1.563
O03 - STREB (PENDERGAST) DVT	-0.156	
O07 - GALLAGHER DVT	-0.445	
I27 - TRAPPER CR	0.068	
TOTAL	**8.704**	**GAINING**
Z10+11 - BIG HOLE RVR NR SALMON FLY FAS	**10.267**	**10.267**
I24 - CHERRY CR	0.092	
R18 - GALLAGHER-STREB RT	0.295	
I40 - KALSTA DVT	-0.334	
O23 - HAGENBARTH-1 DVT	-0.585	-1.135
R37 - ROCK CREEK	0.041	
O22 - HAGENBARTH-2 DVT	-0.174	
TOTAL	**9.602**	**LOSING**
Z12 USGS 06017000 - BH RVR NR MELROSE	**8.467**	**8.467**
I31 - KALSTA RT	0.239	
O20 - GAINY DVT	-0.070	-1.667
EST - GARRISON-KILWIEN DVT	-0.500	
TOTAL	**8.136**	**LOSING**
Z13 - BIG HOLE RVR NR GLEN FAS	**6.469**	**6.469**
R27 - WILLOW CR	0.450	
O10 - STEVENS SLOUGH (GARRISON) DVT	-0.113	
R28 - BIRCH CR	0.025	
O11 - COCANOUGHAR-1 (RAFFERTY) DVT	-0.175	1.886
O12 - COCANOUGHAR-2 (RAFFERTY) DVT	-0.238	
O13 - BRYAN DVT	-0.120	
TOTAL	**6.298**	**GAINING**
Z14 - USGS 06018500 - BH RVR @ NOTCH FAS	**8.184**	**8.184**
O05 - LARSON-NARANICH (JS) DVT	-0.750	-0.864
TOTAL	**7.434**	**LOSING**
Z15 - BIG HOLE RVR ABOVE PAIGEVILLE DVT	**6.570**	**6.570**
R30 - LARSON-NARANCICH RT	0.207	
O14 - SANDY DITCH DVT	-0.133	
O15 - PAIGEVILLE CANAL	-1.642	0.693
I37 - NARANCICH DVT	-0.600	
I38 - SANDY DITCH RT	0.200	
TOTAL	**4.602**	**GAINING**
Z16 - BIG HOLE RVR @ PENNINGTON BR FAS	**5.295**	5.295
I90 - PENNINGTON BR DVT	-0.060	
O17 - OWSLEY SLOUGH (BH COOP)	-2.197	0.345
I41 - PENNINGTON BR RT	0.015	
TOTAL	**3.053**	**GAINING**
Z17 - BIG HOLE RVR ABOVE THIRD SLOUGH	**3.398**	3.398
O18 - THIRD SLOUGH (ORPHAN HOME)	-0.269	
O19 - LOGAN-SMITH DVT	-0.174	-0.059
O21 - LOTT-HARVEY DVT	-0.271	
TOTAL	**2.684**	**LOSING**
Z18+Z19 - BIG HOLE RVR NR HIGH ROAD FAS	**2.625**	2.625
O68 - SIEDENSTICKER (HAMILTON) DVT	-0.049	
O67 - UNNAMED DVT	-0.150	
TOTAL	**2.426**	**LOSING**
CONFLUENCE W/ BEAVERHEAD	NO MEASUREMENT	**END**
Z20 - BEAVERHEAD RVR		4.531
COMBINE - JEFFERSON RVR HEADWATERS		6.957

Notes:
(1) Z01, R02, R48, etc. – field measurement ID (not necessarily in alphanumeric order)
(2) Those field measurement ID's with "A" or "I" prefix estimated in field using floating object method
(3) Z05 (Dickie Bridge) – flow measurement did not meet QA/QC requirements
(4) DVT = diversion
(5) RT = return flow

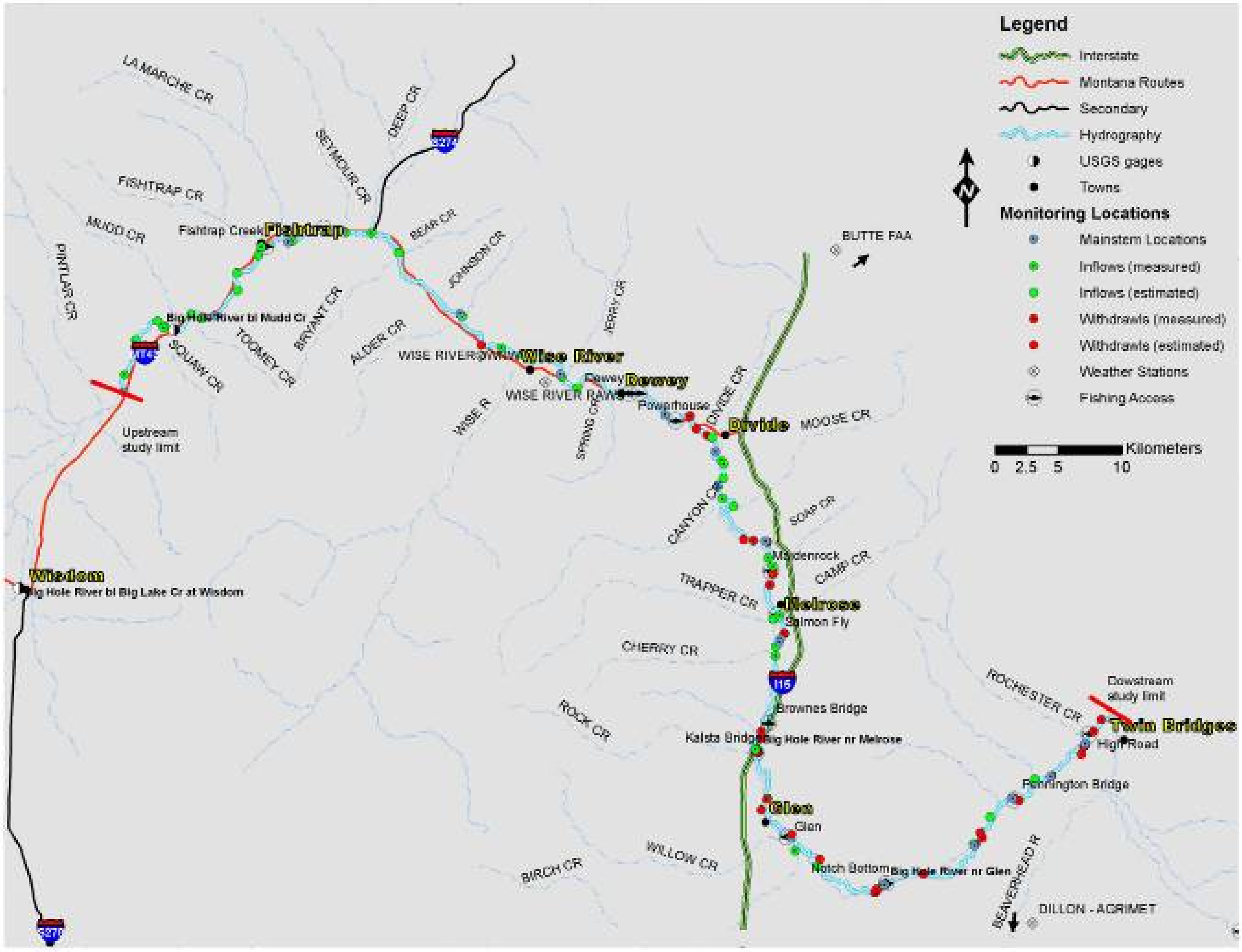


Figure D-5. Locations of major inflow, outflow, and climate monitoring on the Big Hole River.

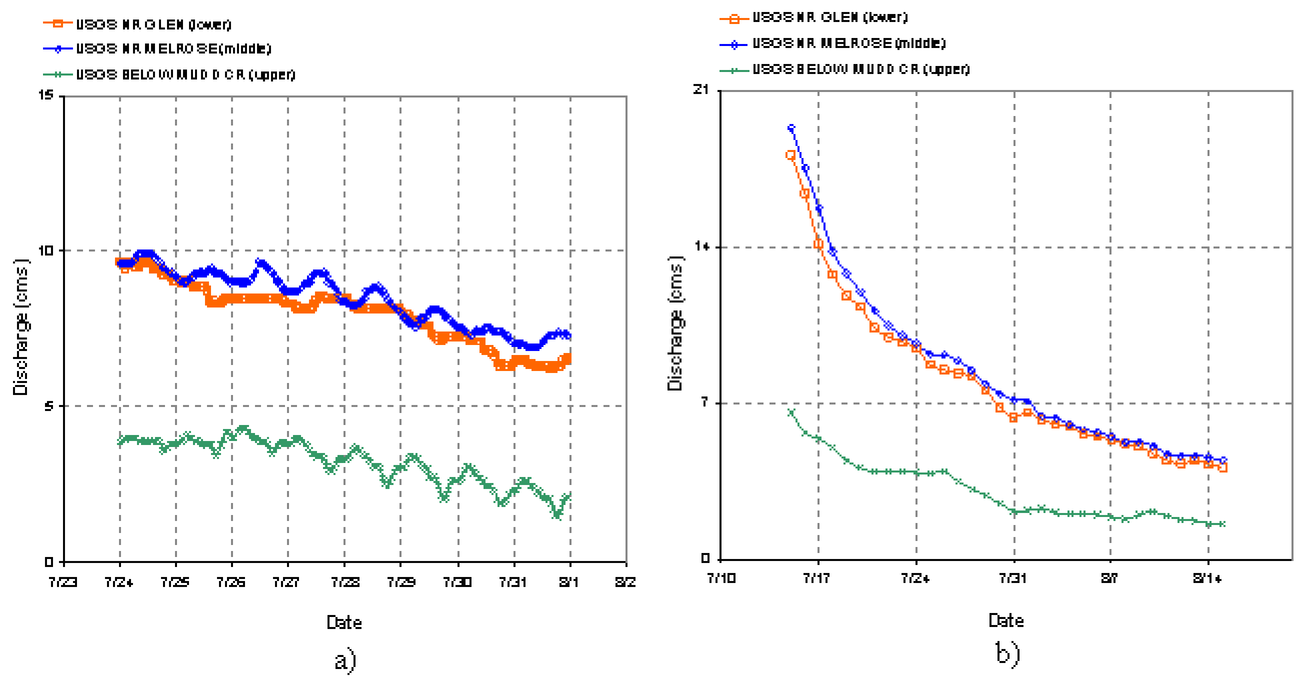
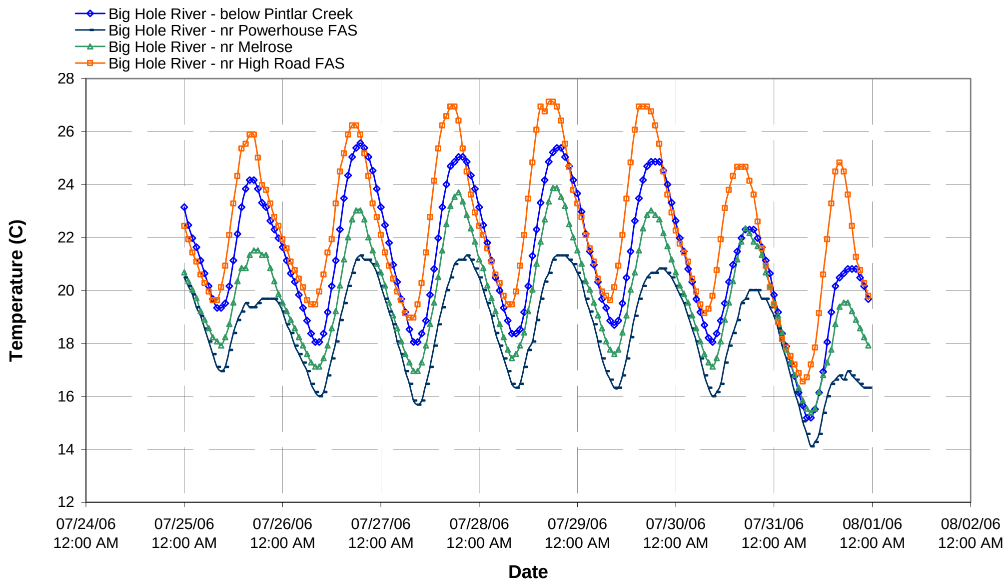


Figure D-6. Streamflow during the critical temperature limiting period a) streamflow during the critical temperature limiting period - 2006; b) hourly plot Jul. 25-31; daily plot Jul. 15-Aug. 15.

While discharge measurements were input as steady-flow (with the exception of the headwater condition), temperature measurements were made as time-variable using data from Hobo temperature loggers. In locations where continuous temperature data were not collected, instantaneous field measurements were completed such that an hourly distribution could be developed from the relationship between instrumented and un-instrumented sites. Aspect, proximity, and contributing watershed area were the primary attributes used in the paired watershed approach. Given the voluminous amount of data collected at these sites, much of it cannot be presented in the text of this report. However, a subset of hourly plots for both mainstem and tributary sites are shown in **fig D-7a** and **D-7b**. In general, tributaries exhibit greater diel fluctuation than mainstem sites. They are also much cooler. In both locations, temperatures reach maximums at approximately 6:00-7:00 p.m., while nighttime minimums occur in the morning at 9:00 to 10:00 a.m.

Box and whisker plots from incoming tributaries to the Big Hole River are shown in **fig. D-8**. While minimums and maximums vary throughout the watershed, it is recognized that irrigation return flows often have a much larger range of maximum and minimum temperatures, and associated quartiles, compared to that of natural tributary flow. This is most likely a function of flow volume at these sites and forms a preliminary understanding of the cumulative influence of irrigation returns on water temperature.

a)



b)

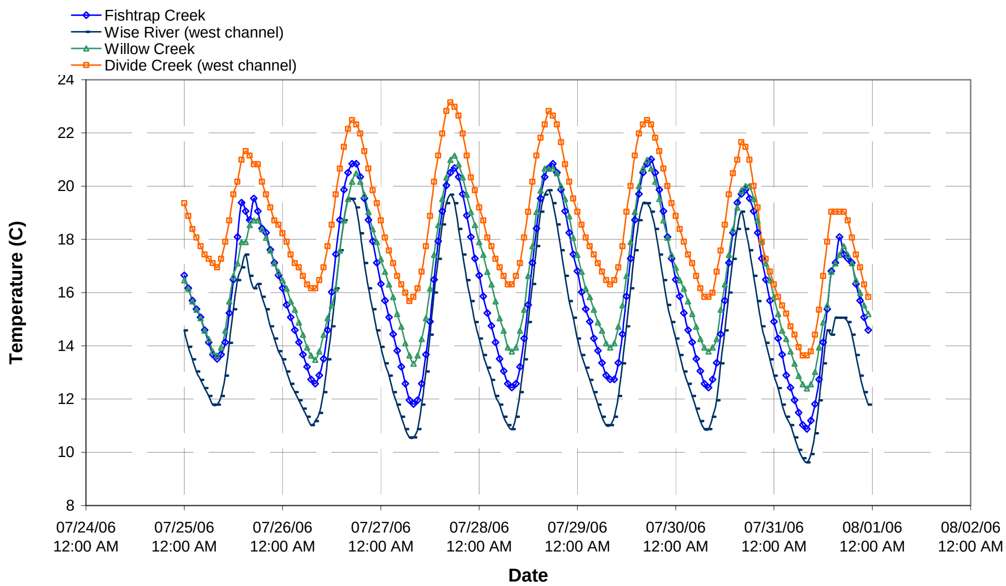


Figure D-7. Hourly plots of water temperature for selected a) mainstem and b) tributary monitoring stations on the Big Hole River for the July 25-31, 2006 monitoring period.

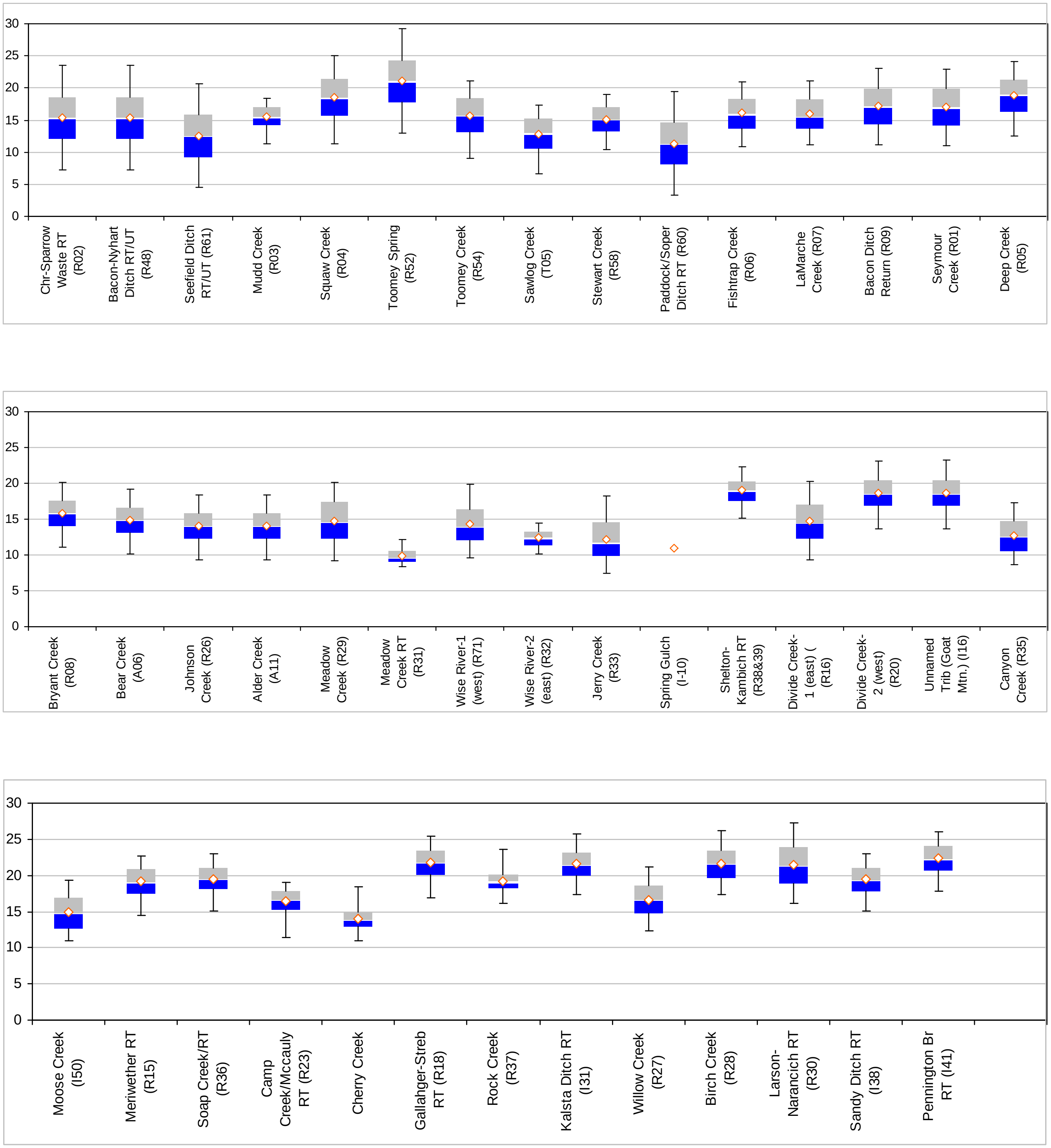


Figure D-8. Box and whisker plots of tributary temperature data collected on the Big Hole River from the July 25-31, 2007. From top left to bottom right, plots are in sequential order going downstream.

Hydraulic Input

Bankfull width, width-depth ratio, channel side slope, gradient, Muskingum routing coefficients, and Manning's roughness coefficients are all required hydraulic inputs for Heatsource v7.0. Unknown variables such as velocity, depth, and wetted channel width are then computed for a given flow condition using Manning's equation and assumed trapezoidal channel geometry. Hydraulic input for the model was developed as follows: (1) bankfull width was measured in the GIS at 100-m intervals using digitized left and right bank polylines as part of the initial TTools processing, (2) width-depth ratio and channel side slope were regressed using measured field parameters, and (3) Manning's roughness coefficient was directly estimated from USGS gage sites using known channel geometry and a wide channel approximation. Roughness values were shown to much higher than those typically published in the literature (0.05-0.14; see Chow 1959; Sturm, 2001). This is reflective of the increasing effect of resistance with decreasing hydraulic depth, filamentous algae, pools and riffles, and other unknown obstructions USACE (1993). Values of 0.09-0.12 were used in the modeling (see **Appendix-A**). Fourteen reaches were identified for unique parameterization of hydraulics based on channel gradient from the USGS NED (**fig. D-9**). They were characterized as shown in **table D-2**.

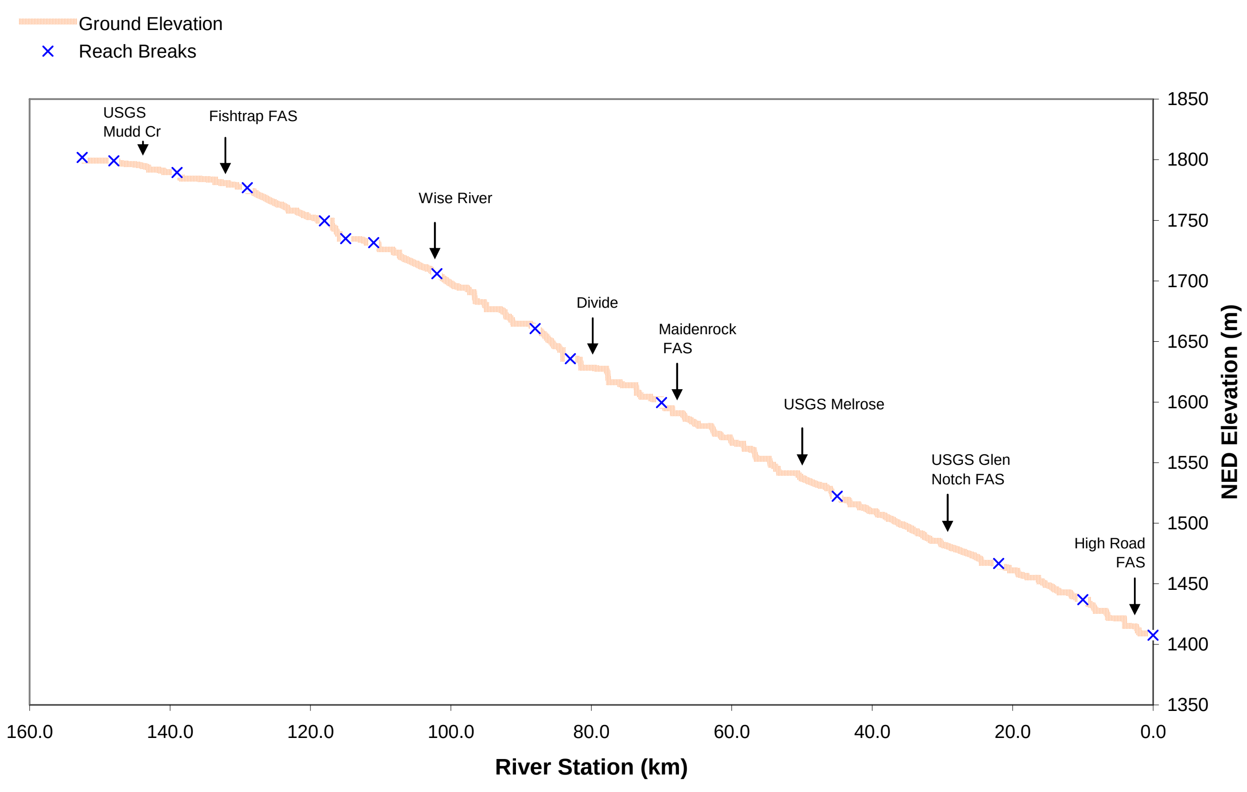


Figure D-9. Unique reaches defined for model parameterization of hydraulics. Elevation data taken from USGS National Elevation Dataset (NED) 30-m grid.

Climate Input

Three climate stations were used to provide hourly temperature (°C), wind speed (m/s), and relative humidity (%) data for the modeling effort. The Wise River RAWS site, Bert-Mooney FAA (e.g. Butte), and Dillon Valley Agrimet station were apportioned to representative modeling reaches to account for localized climate. Because meteorological data collected outside of the river corridor is at times not representative of conditions encountered near the river (Troxler and Thackston, 1975; Bartholow 1989), field measurements taken from within the river corridor were used to perform a climate adjustment. Of all inputs adjusted (e.g. temperature, wind speed, and relative humidity), relative humidity was found to vary the most between locations. At times, it was 15-20 percent greater in the river corridor than at surrounding climate stations. Climate data used in the modeling are shown in **fig. D-10**.

Shade Input

Fifteen riparian landcover types were identified through air photo interpretation and ground-truth to parameterize typical reach shading attributes in the model (**table D-3**). Verified model parameters were then assigned to corresponding land classes to form the base input for radial shading calculations in Heatsource v7.0. An example of the digitized landcover used for this process is shown in **fig. D-11** (near Melrose and the Salmon Fly FAS).

Table D-2. Hydraulic parameters used in the Big Hole River Heatsource v7.0 model.

River Reaches	Gradient (%)	Width- Depth Ratio	Mannings "n"
Reach 1	0.062%	90	0.09
Reach 2	0.108%	80	0.09
Reach 3	0.126%	80	0.09
Reach 4	0.249%	80	0.10
Reach 5	0.490%	70	0.10
Reach 6	0.082%	70	0.10
Reach 7	0.284%	70	0.10
Reach 8	0.324%	70	0.10
Reach 9	0.496%	70	0.10
Reach 10	0.302%	70	0.10
Reach 11	0.297%	60	0.10
Reach 12	0.242%	60	0.10
Reach 13	0.248%	50	0.12
Reach 14	0.293%	50	0.12

Table D-3. Riparian landcover types and associated attributes used in Heatsource v7.0 shading calculations.

Land Cover	Height (m)	Density (%)	Over-hang (m)
Bare	4.9	40%	0.00
Coniferous (sparse)	5.7	75%	0.10
Coniferous (dense)	17.2	40%	0.10
Deciduous (sparse)	18.9	85%	0.30
Deciduous (dense)	14.5	55%	0.00
Grass/sedge (sparse)	16.0	85%	0.00
Grass/sedge (dense)	0.4	50%	0.00
Grass 75%/deciduous 25%	0.5	90%	0.10
NSDZ/water	2.9	64%	0.05
Transportation	11.7	60%	0.13
Willow (sparse)	12.9	63%	0.08
Willow/ (dense)	0.0	0%	0.00
Willow/deciduous	0.0	0%	0.00
Willow/deciduous/conifer	4.9	68%	0.09
Willow 50%/grass 50%	0.0	0%	0.00

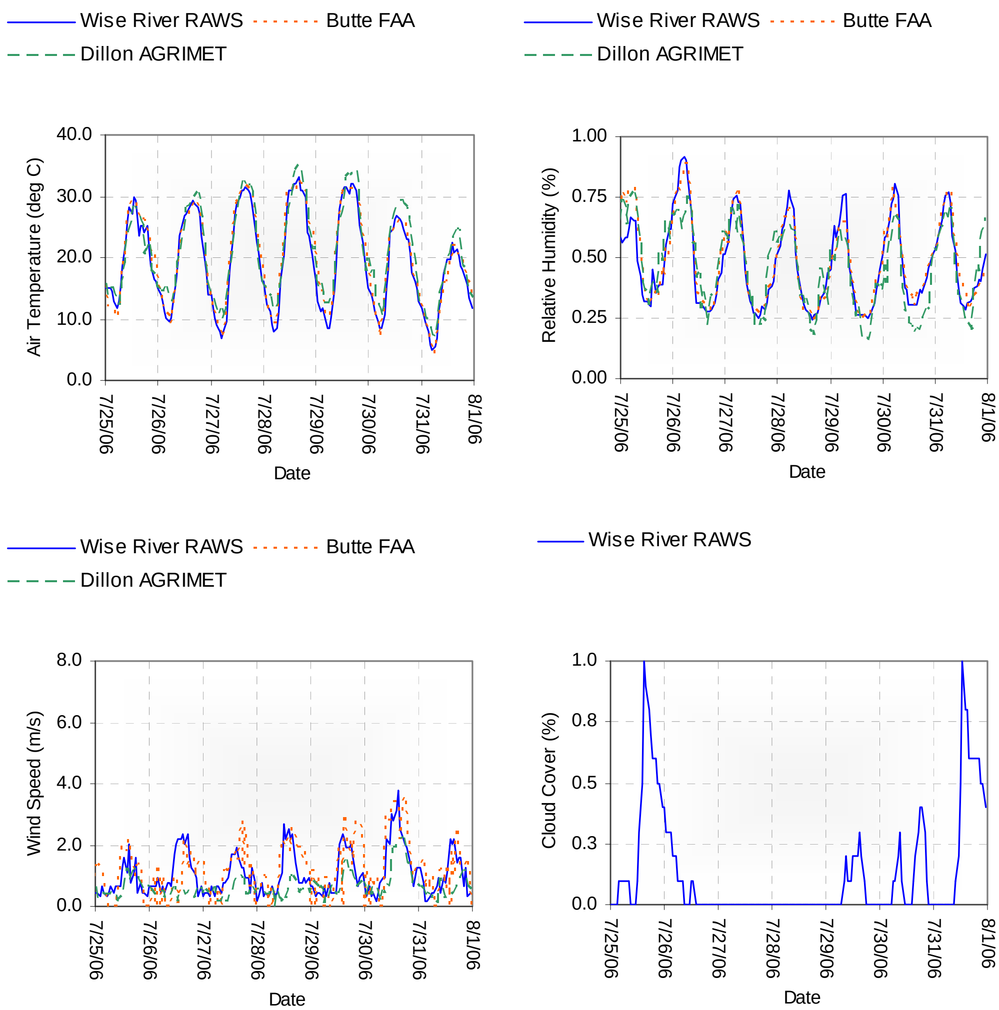


Figure D-10. Adjusted climatic conditions over the July 25-31, 2006 modeling period at the three localized climate stations.

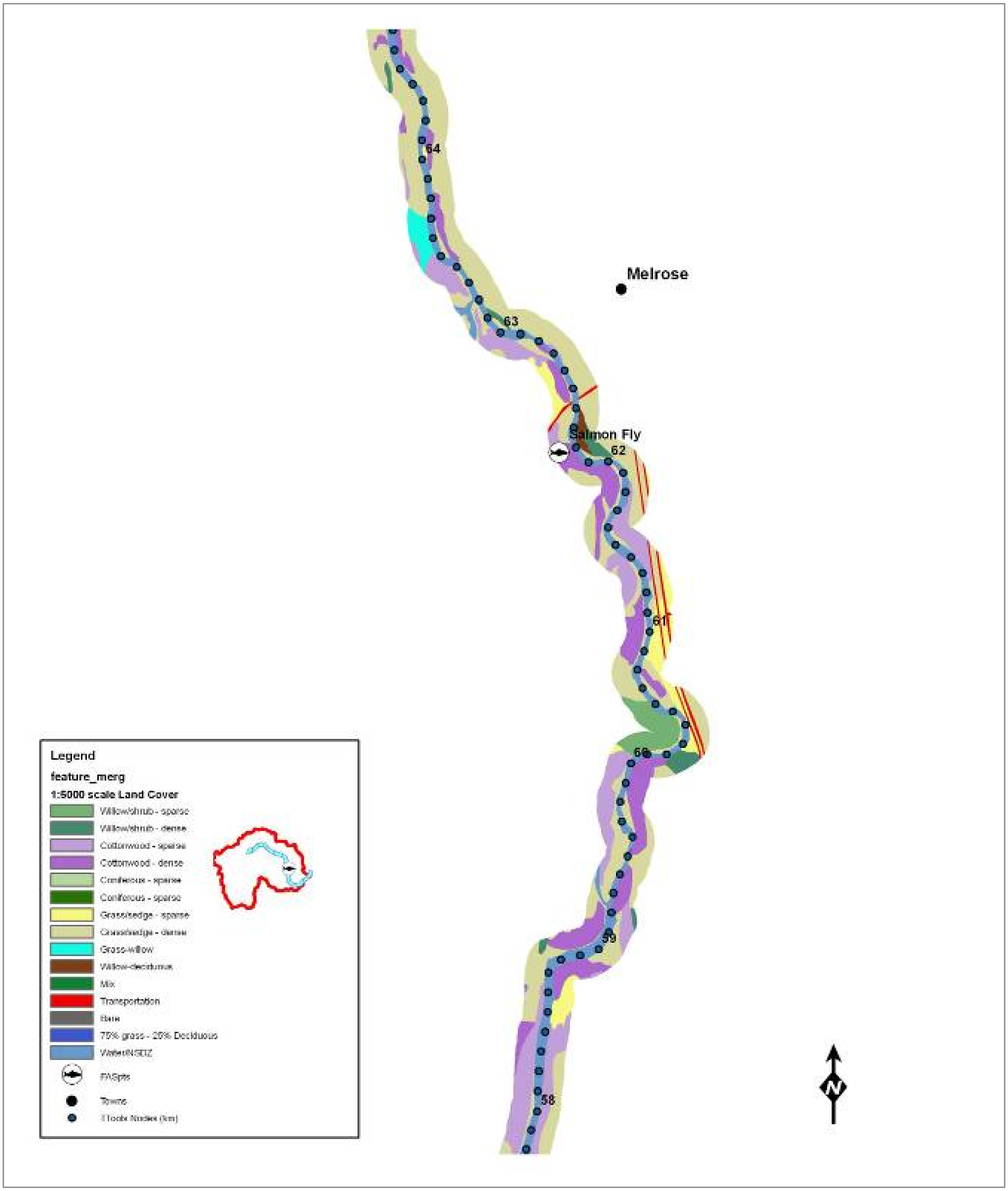


Figure D-11. Example of digitized riparian landcover classification used in the Big Hole River Model near Melrose. The 2004 NAIP imagery was used at a 1:5,000 scale to produce a 1-m raster landcover dataset.

Model Evaluation Criteria

Following model input development, performance statistics were selected to assess hourly and 7-day average temperature predictions from Heatsource v7.0. The first criterion was percent bias (PBIAS), which is a measure of the average tendency of the simulated temperatures to be larger or smaller than an observed value. Optimal PBIAS is 0.0 while a positive value indicates a model bias toward overestimation. A negative value indicates bias toward underestimation. PBIAS is calculated as follows:

$$PBIAS = \frac{\sum_{i=1}^{n} (T_{isim} - T_{iobs})}{\sum_{i=1}^{n} (T_{iobs})} \times 100 \qquad (1)$$

where

PBIAS = deviation of temperature in percent
Tiobs = observed temperature (ºC)
Tisim = simulated temperature (ºC)

DEQ has defined acceptable model bias as less than or equal to ±5 percent, more stringent than typically reported in the literature [Van Liew et al. (2005) and Donigian et al. (1983)]. The second evaluation criterion used in evaluation of model efficiency was the Nash-Sutcliffe coefficient of efficiency (NSE; Nash and Sutcliffe, 1970). NSE expresses the fraction of the measured temperature variance that is reproduced by the model. As error in the model is reduced, the NSE coefficient is inherently increased. Simulation results are considered to be good for NSE > 0.75, while values between 0.75 and 0.36 are considered satisfactory (Motovilov et al. 1999). NSE is calculated as:

$$NS_E = 1 - \frac{\sum_{i=1}^{n} (T_{iobs} - T_{isim})^2}{\sum_{i=1}^{n} (T_{iobs} - T_{avg})^2} \qquad (2)$$

where

NSE = coefficient of efficiency
Tavg = average simulated temperature (ºC)

A final criterion used in the Big Hole River modeling is the sum of squared residuals (SSR), which is a commonly used objective function for hydrologic model calibration. It compares the difference between the modeled and observed ordinates, and uses the squared differences as the measure of fit. Thus a difference of 2°C between the predicted and observed values is four times worse than a difference of 1°C. Squaring the differences also treats both overestimates and underestimates by the model as undesirable. The equation for calculation of SSR is shown below (Diskin and Simon, 1977).

$$SSR = \sum_{i=1}^{n} (T_{iobs} - T_{isim})^2 \qquad (3)$$

where

SSR = sum of squared residuals

Sensitivity Analysis & Model Uncertainty

Model uncertainty was assessed using a simple one-at-a-time (OAT) sensitivity analysis with parameter perturbations of ±10 percent and ±30 percent. The OAT methodology ensures that changes in output can unambiguously be attributed to the changes in model input. Parameter sensitivity is typically expressed as a normalized sensitivity coefficient (NSC) as shown below (Brown and Barnwell, 1987).

$$NSC = \left| \frac{\Delta Y_o / Y_o}{\Delta X_I / X_I} \right| \qquad (4)$$

where

NSC = normalized sensitivity coefficient
ΔYo = change in the output variable Yo
ΔXi = change in the input variable Xi

NSCs for model parameters in Heatsource v7.0 are shown in **table D-4** and are taken as the average results of the four sensitivity runs for the most downstream modeling node (±10 percent and ±30 percent perturbations). Results indicate that parameters directly related to heat flux or mass transfer (ground temperature, air temperature, relative humidity, groundwater flow, and tributary flow) are highly sensitive in the Big Hole River watershed. Those related to flow routing were not (roughness, Muskingum-x, width-depth ratio, etc.). Given knowledge of parameter sensitivity, model prediction error and associated uncertainty were qualified as moderate- to highly-certain for the project. This is largely due to the fact that the most influential model input parameters were fairly well known (either directly measured or estimated in the field) while those that were relatively in-sensitive, were not. No other efforts were made to assess uncertainty as part of this project.

Table D-4. Summary of parameter sensitivity for the Big Hole River Heatsource v7.0 model.

Parameter	Rank	NSC
Ground temperature (ºC)	1	0.24
Air temperature (ºC)	2	0.21
Relative humidity (%)	3	0.12
Groundwater Q (cms)	4	0.07
Tributary Q (cms)	5	0.07
Groundwater temperature (ºC)	6	0.06
Wind speed (m/s)	7	0.04
Mass transfer “a” coefficient	8	0.03
Cloud cover (%)	9	0.03
Irrigation diversion (m/s)	10	0.03
Tributary temperature (ºC) Bankfull width (m) Headwater Q (cms) Manning’s “n” (dimensionless) Shade density (%) Width-depth ratio Channel z-angle (1:z) Headwater temperature (ºC) Particle size (mm) Muskingum “x” (dimensionless) Bed Ks (mm/s) Embeddedness (%)		<0.03

Model Calibration Procedure

The Big Hole River Heatsource v7.0 model was calibrated in an iterative fashion, from up- to downstream, based on the evaluation criteria identified previously. Generalized information related to model calibration can be found in Thomann (1982), James and Burges (1982), and ASTM (1984). Meteorological forcing data were first assessed as part of the calibration for artifacts of unrepresentative input data, e.g. where the model consistently has anomalous over- or under-prediction for only a portion of the simulation period. Cloud cover was the primary calibration parameter used in this instance. Additional calibration parameters included wind speed, groundwater accretion temperature, and Manning’s roughness coefficient. All were adjusted within a reasonable range such that agreement between observed and simulated values occurred. Final calibrated reach parameters are shown in Attachment-A. Subsequent PBIAS, NSE, and SSR values for the temperature calibration are described in the Results and Discussion section.

Model Validation/Confirmation

After calibration, a model should be validated or confirmed against an independent dataset. This effectively demonstrates that the model performs adequately over a range of conditions beyond that which it was calibrated to (Barthalow, 1989; Chapra and Reckow, 1983; Chapra, 1997). Unfortunately, independent data outside of the 2006 field effort do not exist for validation purposes largely due to the dynamic conditions encountered in the watershed. Therefore, several auxiliary lines of evidence were evaluated in a "low-level" confirmation exercise. This included: (1) an in-depth comparison of calculated physical subroutines in the model with that of field observations (e.g. hydrology, hydraulics, and shading discussed in subsequent sections) and (2) assessment of appropriate in-stream water temperature responses to varying climatic conditions.

RESULTS & DISCUSSION

Hydrology

Simulated streamflow for July 28th of the July 25-31, 2006 modeling period is shown in **fig. D-12**. Inspection of the observed and predicted values shows very good agreement. Hydrology is within ±5 percent at all monitoring nodes, and mean prediction PBIAS and standard error were +0.4 percent and 0.2 cms respectively (comparing daily simulated flow values with instantaneous field-measurements). Clearly, surface water hydrology is a function of the combined influence of tributary inflow, irrigation withdrawal and return flow, split channel flow (e.g. braiding), and localized groundwater accretion. Major surface water inflows occur in the Fishtrap, LaMarche, and Deep Creek and Wise River areas, and geological valley controls such as the Greenwood Bottoms, Maidenrock Canyon, and Notch Bottom provide substantial groundwater accretion. A large portion of the dewatering occurs in the lower reaches between Notch Bottom FAS and the High Road FAS near Twin Bridges.

In review of the water balance, little, if any, groundwater discharge to surface water occurs during the modeling period. This is consistent with the findings of Marvin and Voller (2000) who suggest that during the summer months, a majority of the irrigation losses from leaky ditches and flood irrigation are consumed by ET rather than returning to surface water through groundwater flow. Groundwater influx in the Big Hole River watershed does occur in two instances: (1) where large groundwater flow systems converge and intersect with the Big Hole alluvial aquifer, and (2) where geological valley controls contract the effective subsurface flow area causing pinching and localized expression of surface water. This influx is followed by immediate losses in the downstream direction as the valley expands. Both mechanisms of groundwater accretion/hyporheic exchange have been previously documented in the literature (Stanford and Ward, 1993; Ward et al., 1999; Malard et al; 1999). The regional alluvial aquifer convergence mentioned previously occurs in the Big Hole River near Fishtrap, LaMarche, and Deep Creeks (river km 132-122), near Wise River (km-102), and by Glen (km 68-58). Geological controls occur at Greenwood Bottom, Maiden Rock Canyon, and Notch Bottom (river km-88.5, 72.5, and 7.5 respectively).

Hydraulics

Correct simulation of river hydraulics ensures that the air-water interface and associated water column are exposed to an accurate duration of meteorological forcings within the model. A comparison of model hydraulics against measured field data for confirmation purposes is shown in **fig D-13**. In general, good agreement is seen between observed and simulated values. Mean PBIAS for computed channel velocities, wetted widths, and associated depths were -5.3 percent, 4.6 percent, and 19.9 percent respectively. Standard errors were and 0.08 m/s and 10 and 0.1 meters respectively. These are adequate given the gross simplification of channel geometry in Heatsource v.7.0 in contrast to more detailed hydraulic models.

Shade

Simulated stream shade includes shading from both topography and vegetation and integrates the effects of channel aspect, offset, and width at a particular model node. Stream shade predictions ranged from 1 to 36 percent at individual model nodes, and averaged 5.7 percent for the entire study reach. Overall simulation PBIAS was 3.5 percent with a standard error (in percent shade) of 4 percent. While this is not great, when compared to site specific observations taken with a solar pathfinder, model simulation values are within reason (**fig. D-14**). Modeled shade appears to track well with observed measurements and shows several distinct shading peaks occurring at river km-130, 80, and 50. These are a function of topography rather than vegetation, and correspond to topographic angles of greater than 10-degrees. Discrepancies between simulated and observed values exemplify the difference between measured point values and averages over the 1,000-m distance step.

Water Temperature

With concurrence between hydrology, hydraulics, and shade, it was expected that simulated water temperatures in Heatsource v7.0 would be in good agreement with observed values. Computed and observed minimum, mean, and maximum water temperatures for July 28th of the July 25-31, 2007 modeling period are shown in **fig. D-15**. Hourly diurnal plots are in **fig. D-16**. Overall, there is excellent agreement between both. In review of the calibration statistics, PBIAS was largely negligible (0.2 percent), hourly NSE was 0.88, SSQR = 51.49, and standard error = 0.6°C. Individual calibration statistics for modeling nodes are shown in **table D-5**.

Examination of the longitudinal profile of the Big Hole River provides significant information regarding in-stream water temperatures, and associated system dynamics. Beginning at the upstream boundary, temperature remains relatively constant until reaching Fishtrap, LaMarche and Deep Creeks. Significant cooling occurs, attenuates, and then occurs again near Wise River due to groundwater accretion and topographic shading. Much of the rest of the reach is characteristic of warming conditions. Temperatures reach 27°C (80.6°F) prior to reaching the confluence with the Beaverhead River.

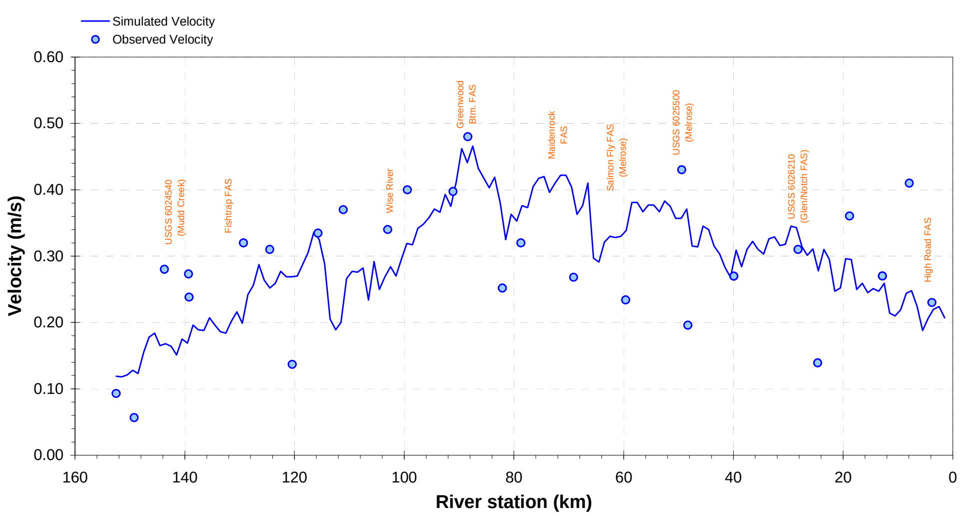
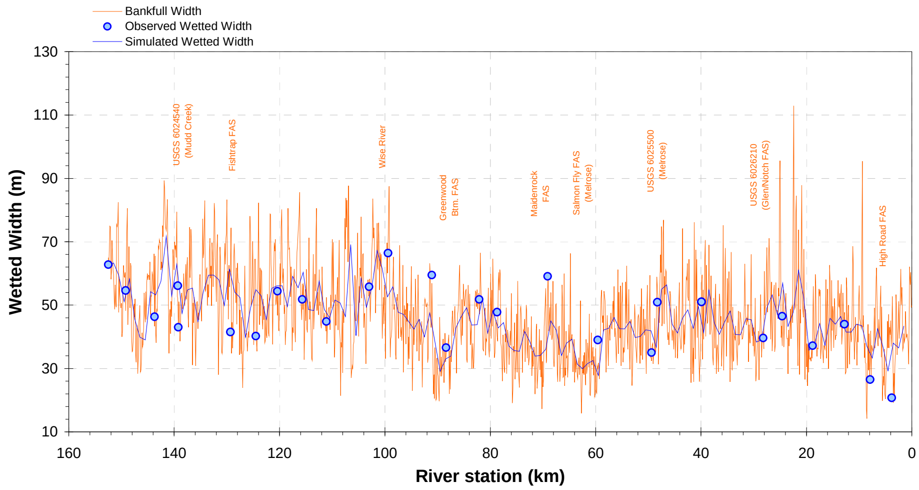
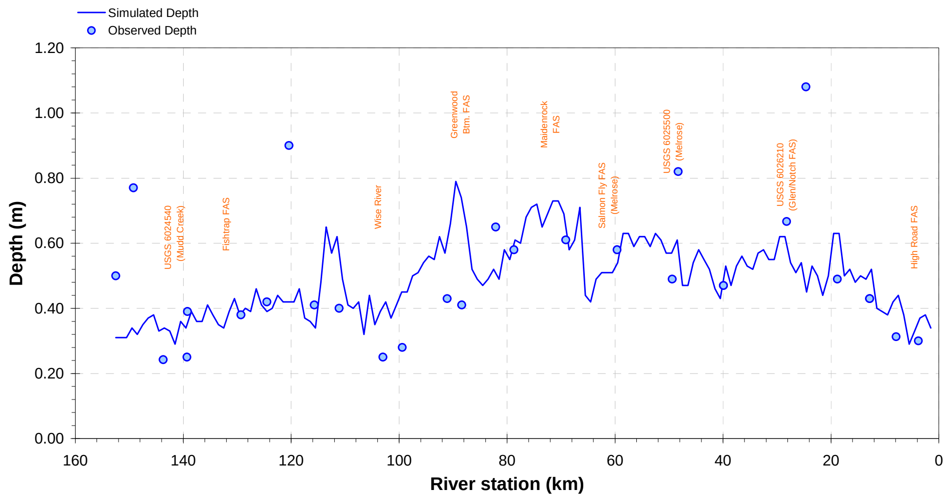


Figure D-12. Big Hole River simulated and observed hydrology for July 28th of the July 25-31, 2006 modeling period. Observed measurements were taken instantaneously over the 7-day study period and may not necessarily reflect conditions that day.

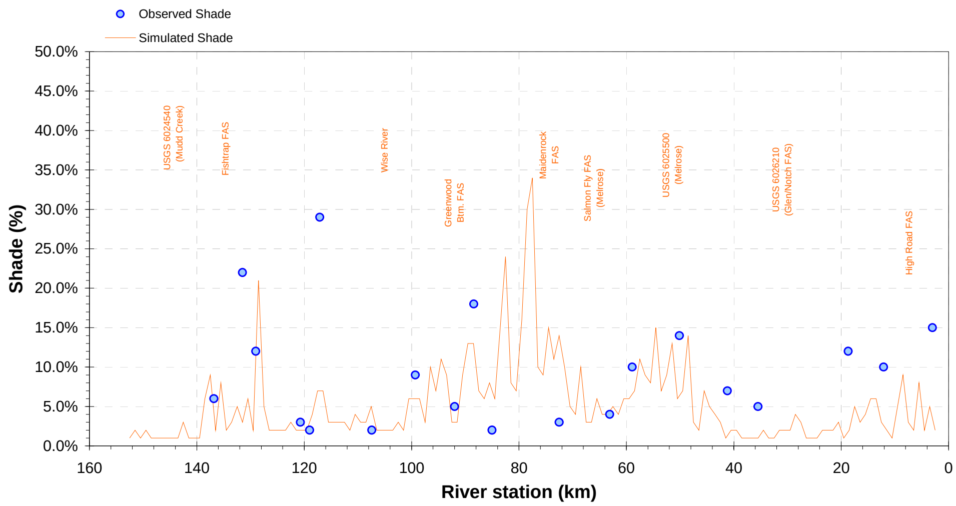
Figure D-13. Big Hole River simulated and observed hydraulics: a) mean velocity, b) mean wetted channel width, and c) mean hydraulic depth for July 28th of the July 25-31, 2006 modeling period. Observed measurements were taken instantaneously over the 7-day study period and may not necessarily reflect conditions that day.



a)



b)



c)

From further review of **fig. D-15**, the relationship between in-stream flow volume and associated water temperatures is apparent. As flows diminish, temperature increases. Rates of warming specifically increase in three instances: (1) in the upper reaches from low flow headwater conditions, (2) in several of the split flow locations due to a decrease in volume and increase in wetted surface area (e.g. river km 59.5 and 39.5), and (3) in the lower 40-km where much of the dewatering occurs. That said, the most heavily warmed sections are the upper and lower reaches. In both areas, temperatures exceed the UILT for Arctic Grayling (25ºC, 77ºF) and also are elevated above that which have been shown to cause the breakdown of physiological bodily processes for salmonid species (Boyd and Kasper, 2004). Fortunately, temperatures are moderated in center of the watershed by groundwater influx and shading, otherwise extremes in the lower watershed would be much more severe.

In calibration of surface water temperature (both the longitudinal profile and diurnal plots), groundwater accretion temperature was found to vary depending on the method of accretion. In areas where large alluvial groundwater systems converged, a temperature of 11°C (51.8°F) was used. This is consistent with temperatures reported by Marvin and Voller (2000) for groundwater in the Big Hole basin as well as those found in a 2007 query of the Groundwater Information Center (GWIC) database. In instances where both regional groundwater flow and geological controls occur, a temperature of 16°C (60.8°F) was used. For areas with consistent hyporheic exchange due to oxbowing and valley morphological controls, a temperature of 19°C (66.2°F) was used. Results are consistent with Boyd and Kasper (2004), Malard et al., (2001), Constantz and Thomas (1997), and Siliman and Booth (1993) who all indicate that shallow groundwater/hyporheic water temperatures are warmer than deep cold subsurface flows, and tend to be influenced by infiltrating stream water, thereby closely patterning diel surface water temperature fluctuations.

Overall, a very good surface water temperature calibration was achieved based on model statistical efficiency. Scenarios for TMDL planning and analysis are described in the following sections.

Table D-5. Hourly water temperature calibration statistics for July 25-31, 2006 modeling period.

Site ID	PBIAS	NSE	SSR	SE
RIVER KM – 139.2 (Z02)	-0.7%	0.91	45.73	0.7
RIVER KM – 129.3 (Z03)	-4.3%	0.82	116.83	0.6
RIVER KM – 124.5 (Z04)	-2.4%	0.87	75.06	0.7
RIVER KM – 115.7 (Z05)	-0.4%	0.91	47.97	0.7
RIVER KM – 111.1 (Z06)	2.3%	0.87	73.52	0.5
RIVER KM – 103.0 (Z22)	1.6%	0.84	92.38	1.0
RIVER KM – 99.4 (Z07)	1.8%	0.91	47.02	0.6
RIVER KM – 87.6 (Z46)	0.8%	0.79	57.85	0.8
RIVER KM – 82.1 (Z21)	0.6%	0.91	24.32	0.5
RIVER KM– 78.7 (Z08)	1.5%	0.90	27.91	0.5
RIVER KM – 69.1 (Z09)	1.7%	0.84	52.04	0.6
RIVER KM – 59.6 (Z10)	1.5%	0.86	52.48	0.7
RIVER KM – 49.4 (Z12)*	2.0%	0.86	46.80	0.6
RIVER KM – 39.9 (Z13)	1.4%	0.84	54.10	0.8
RIVER KM – 28.2 (Z14)*	-1.2%	0.93	22.11	0.4
RIVER KM – 18.8 (Z15)	-0.2%	0.93	22.37	0.5
RIVER KM – 12.8 (Z16)	-0.2%	0.91	28.05	0.6
RIVER KM – 07.9 (Z17)	-0.5%	0.88	40.69	0.6
RIVER KM – 03.7 (Z19)	-1.8%	0.91	51.01	0.7
AVG	0.2%	0.88	51.49	0.6

*Located at USGS gage sites

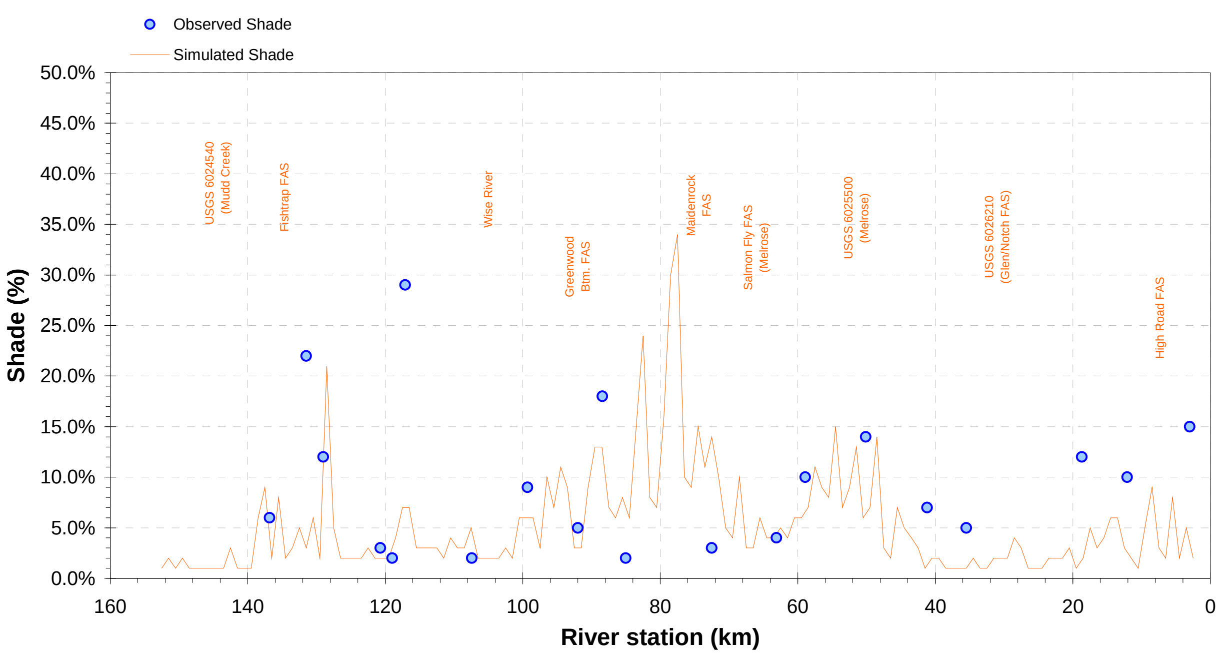


Figure D-14. Big Hole River simulated and observed shade for July 28th of the July 25-31, 2006 modeling period.

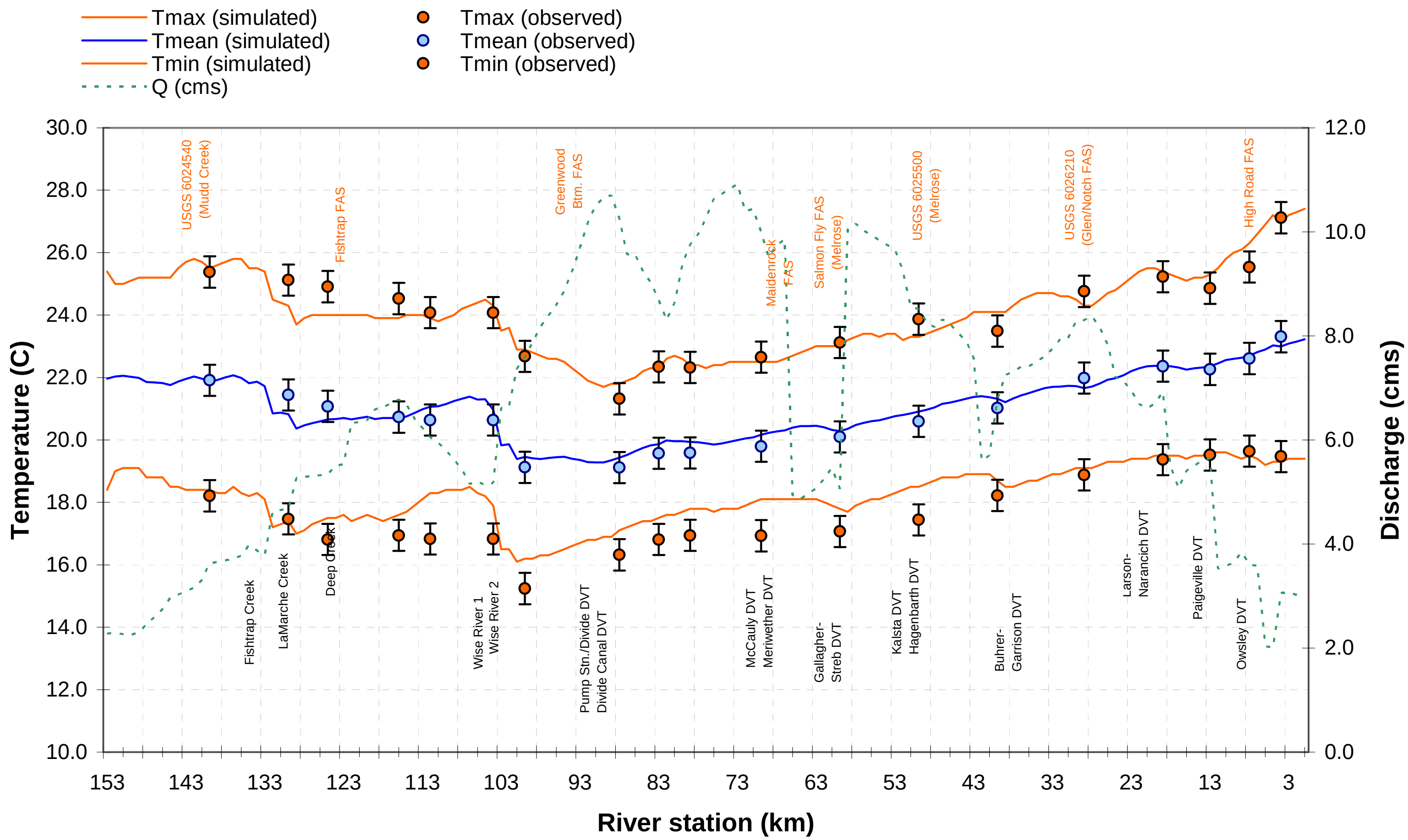
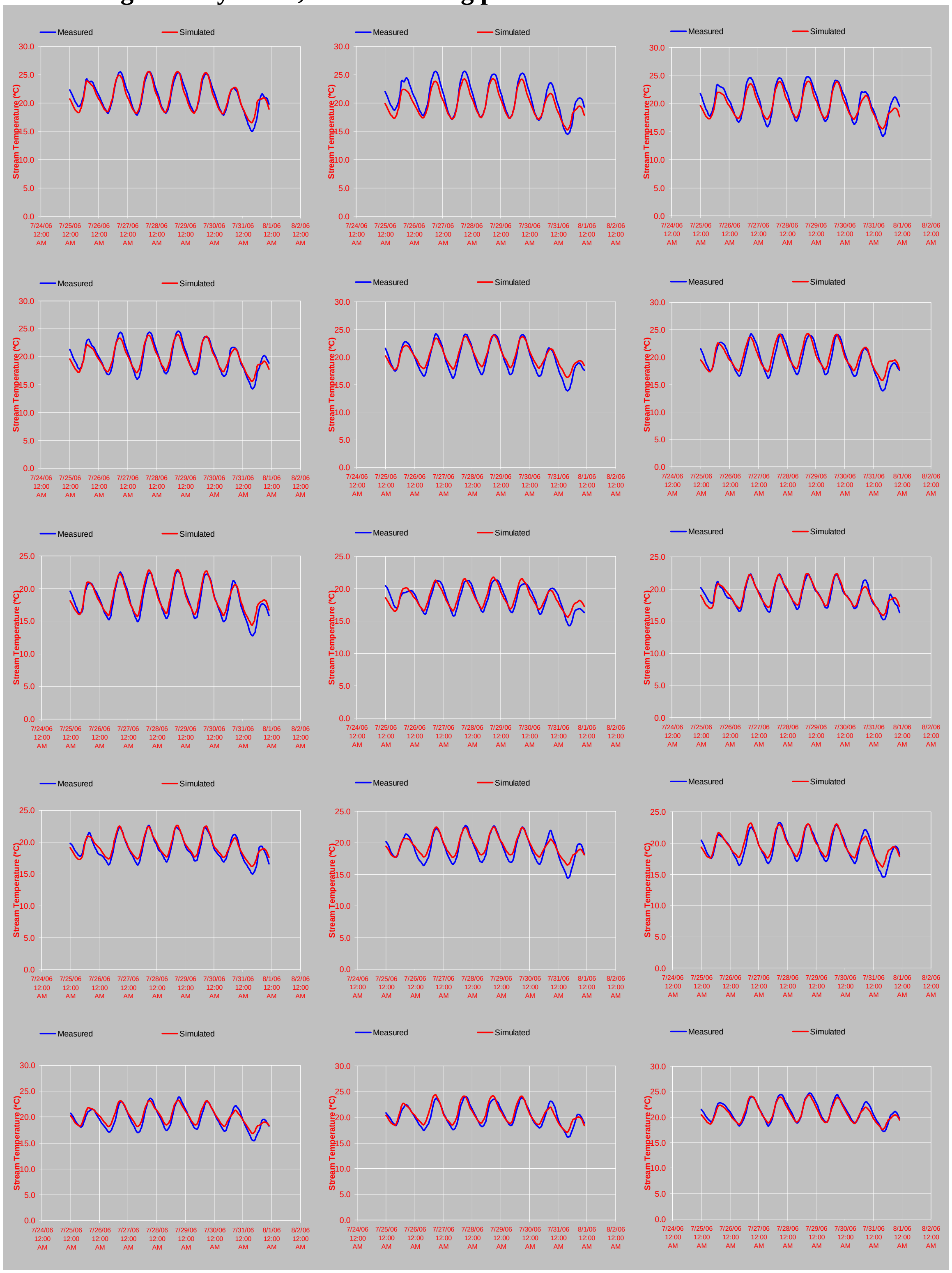
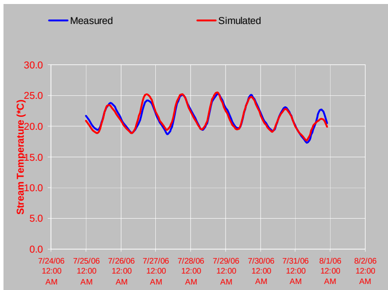
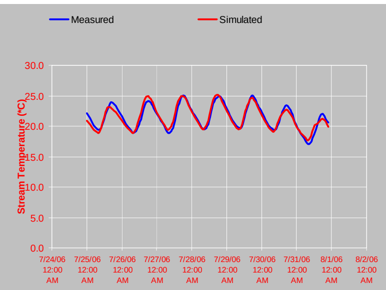


Figure D-15. Longitudinal temperature profile of the Big Hole River displaying Tmin, Tmax, Tavg, and mean discharge for July 28th of the July 25-31, 2006 modeling period. Error bounds of measured data (±0.2 ºC datalogger accuracy) are shown along with major inflows and outflows.

Figure D-16. Diurnal plots of observed and simulated temperature for the 19 monitoring stations on the Big Hole River during the July 25-31, 2006 modeling period.




Measured
Simulated
Stream Temperature (°C)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
7/24/06 12:00 AM
7/25/06 12:00 AM
7/26/06 12:00 AM
7/27/06 12:00 AM
7/28/06 12:00 AM
7/29/06 12:00 AM
7/30/06 12:00 AM
7/31/06 12:00 AM
8/1/06 12:00 AM
8/2/06 12:00 AM


Measured
Simulated
Stream Temperature (°C)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
7/24/06 12:00 AM
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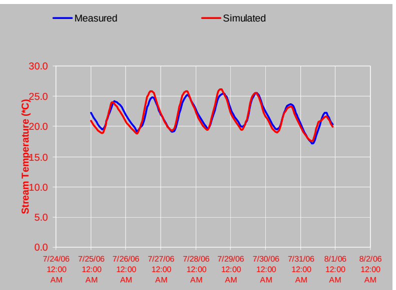
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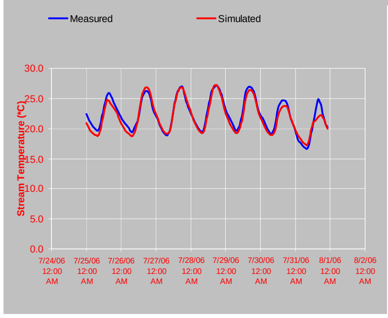
Measured
Simulated
Stream Temperature (°C)
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SCENARIO ANALYSIS

A number of scenarios were developed as part of this study so that watershed managers can provide reasonable recommendations for meeting water quality criteria in the river. Vegetation losses from the riparian corridor, natural channel mophometry, and irrigation withdrawals have all been cited as causes for elevated water temperature in the Big Hole River (DEQ, 2004). However, little has been done to associate management activities in the river corridor with in-stream temperatures. Specifically, modeling scenarios were formulated to address the following: (1) baseline conditions, (2) a shade scenario in which reference shade is applied across the project reach, (3) a morphology scenario where channel mophometry is assumed to be under reference conditions, (4) water consumptive use scenario where effects of irrigation and domestic withdrawls are assessed, (5) a natural condition scenario with no anthropogenic influence, (6) naturally occurring scenario in which all reasonable land, soil, and water conservation practices are applied (ARM 17.30.602), and (7) a use attainment scenario where the model is applied toward a specific BMP for illustrative purposes.

Baseline Scenario

The baseline scenario describes existing conditions in the watershed and is merely a reflection of the calibration. In review, baseline modeling was completed during drought and in low flow conditions approaching the 7Q5. The simulation results have been documented in prior sections and indicate a very good water temperature calibration based on performance statistics of NSE, PBIAS, and SSR. Water temperature was shown to decrease from the upstream study limit to approximately Wise River, and then increase thereafter. Simulated values from the baseline scenario form the basis for which all other scenarios will be compared. For the rest of the document, temperature comparisons are reported as the 7-day minimum (7Dmin), 7-day average (7Davg), and 7-day maximum (7Dmax) water temperature.

Shade Scenario

During the field reconnaissance, the riparian corridor was characterized as being in good condition, with little observed disturbance. In order to exclude shade as a viable control on water temperature in the Big Hole River, a hypothetical shading scenario was run to characterize the maximum possible influence of shade on in-stream temperature. The following assumptions were made in the shade scenario: (1) all open/grassed sites, barren areas, and any other area with diminished shading vegetation was assumed to be converted to reference shade condition and (2) all other conditions were held constant. Reference shade was defined as the combination of 80 percent willow and 20 percent grass in the upper study reach (e.g. km 152.5-102.0) and a mix of 30 percent cottonwood gallery and 70 percent grass cover in the lower 102 km. The breakpoint for the vegetation change was Wise River, which is a clear demarcation in regard to hydrology, climate, and associated soils.

In addition to these changes, a secondary component was integrated into the modeling to assess the influence of upstream shading on the headwater boundary condition of Heatsource v7.0. A SSTEMP model from a previous study (DEQ, upper Big Hole River TMDL unpublished) was linked with Heatsource v7.0 so that the influence of upstream management activities could be propagated downstream. SSTEMP is single segment model that operates on a daily time step and computes many of the same heat flux components as Heatsource v7.0. In total, 94.5 km of river outside of the detailed study reach were evaluated. The model originated at the watershed headwaters and extended as far downstream as Pintlar Creek (e.g. upper TPA boundary). A zero flow headwater condition as described in Barthalow (1989) was used to calibrate SSTEMP water temperature to project hydrology and meteorology. Model assumptions for the SSTEMP shading scenario were as follows: (1) shade was assumed to be at reference condition in the upper TPA as identified by willow cover of height 4-m, crown of 1-m, density of 43%, and offset of 0.5-m (DEQ, upper Big Hole TMDL unpublished), and (2) all other conditions remained constant.

Baseline and simulated shade, along with associated in-stream water temperatures at the outlets of the upper and lower TPAs are shown in **table D-6** and **fig. D-17a**. Average shade in the upper TPA increased significantly, from 3.5 percent to 11.3 percent. Shade in the middle-lower TPA increased only 0.9 percent (5.7 percent to 6.6 percent). This translates into decreases of 0.38 and 0.82°C (0.68 and 1.48°F) in 7Dmin and 7Dmax at the upper TPA boundary while decreases of only 0.03 and 0.06°C (0.05 and 0.11°F) were observed at the watershed outlet near Twin Bridges (lower TPA). Clearly, shade is of great importance to localized conditions in the upper TPA (e.g. near the headwater boundary) but has little effect on the rest of the river. Standard violations were shown to extend 6-km into the detailed study reach, although these quickly attenuate as the river re-adjusts to meteorological and associated mass-transfers conditions in the Fishtrap Creek area. No other exceedances were observed in the middle or lower TPAs. Results strongly suggest that shade, while important to upper basin thermal dynamics, is not an integral component of the heat balance in the middle and lower Big Hole River TPAs. Thus shade improvement is not recommended as an alternative for temperature restoration strategies in the middle and lower basin. It should, however, be considered in the upper TPA to mitigate impairments near the upper detailed study reach boundary (e.g. first 6-km).

Table D-6. Temperature changes at end of simulation reach resulting from modification of shade on the Big Hole River (both SSTEMP and Heatsource v7.0 modeled segments).

Condition	% Shade	Tmin	Tavg	Tmax
Baseline (94.5-km)	3.5%	17.05	21.18	25.31
Shade Scenario	11.3%	16.67	20.58	24.49
Δ TEMP-Uppr TPA		-0.38	-0.60	-0.82
Baseline (152.5 km)	5.7%	18.93	22.17	25.59
Shade Scenario	6.6%	18.90	22.12	25.53
Δ TEMP-Lowr TPA		-0.03	-0.05	-0.06
Δ TEMP – all (1)		-0.04	-0.05	-0.05

(1)Average deviation of all model nodes, not just watershed outlet

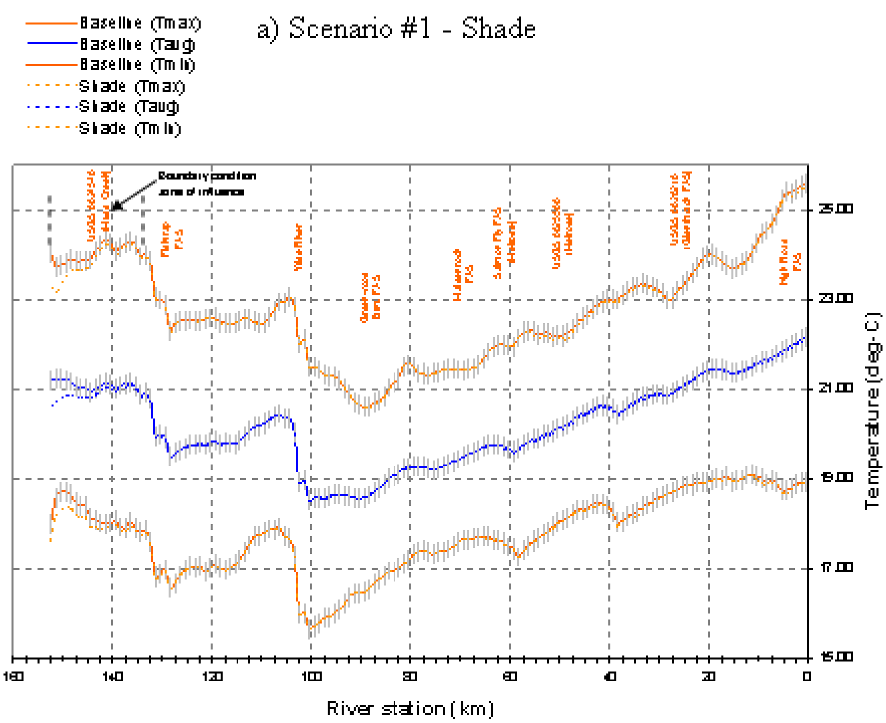
Channel Morphology Scenario

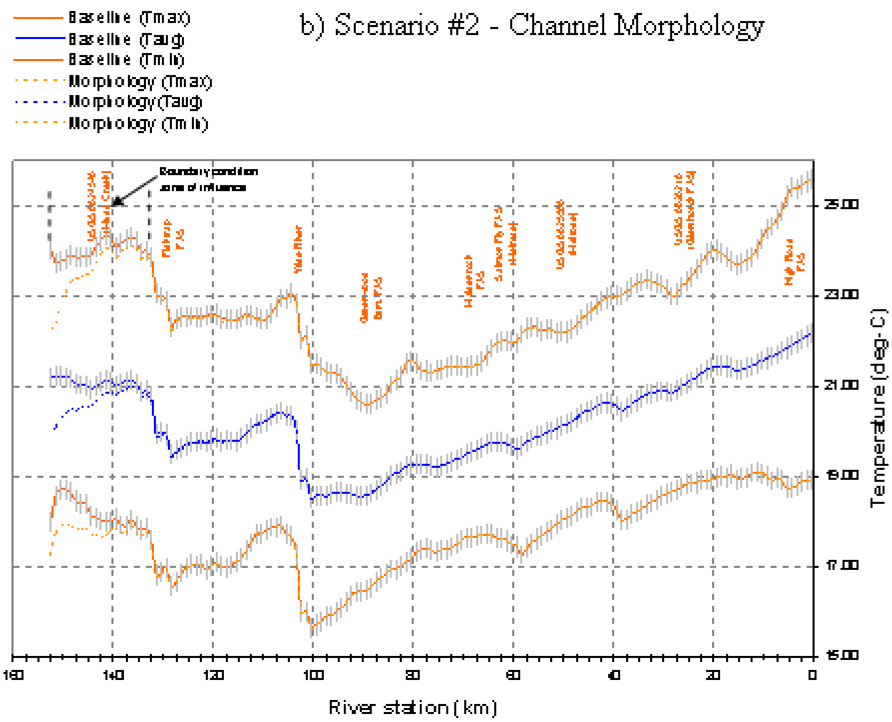
A channel morphology scenario was also completed to assess the influence of physical geometry on the overall heat balance of the reach. Similar to the shade scenario, both SSTEMP and Heatsource were used for this purpose. A coarse parameterization was completed to identify whether the wide reaches of the Big Hole River (width-depth ratios approaching 80 and 90) could potentially be altered to reduce the air-water interface, and subsequently, lower in-stream temperatures. Model parameterizations were formulated using targets from DEQ (upper Big Hole TMDL unpublished) and included the following assumptions: (1) width-depth ratios in the upper TPA were reduced by 30 percent, (2) width-depth ratios over 60 in the lower 152.5 km were set to 60, and (3) all other model parameters were held constant. Results of the SSTEMP model runs show that substantial reductions (up to 1.79°C; 3.22°F in 7Dmax) can be achieved at upstream end of the project reach (**table D-7**). This effect quickly reverts back toward baseline though as the water column is subjected to prolonged exposure of atmospheric conditions (**fig. D-17b**). Because changes are short lived, and do not propagate into the heavily warmed lower sections of the river, morphology modification is not recommended as suitable mechanism for controlling in-stream temperatures in the lower Big Hole River TPA. It does remain a viable option upstream of Pintlar Creek.

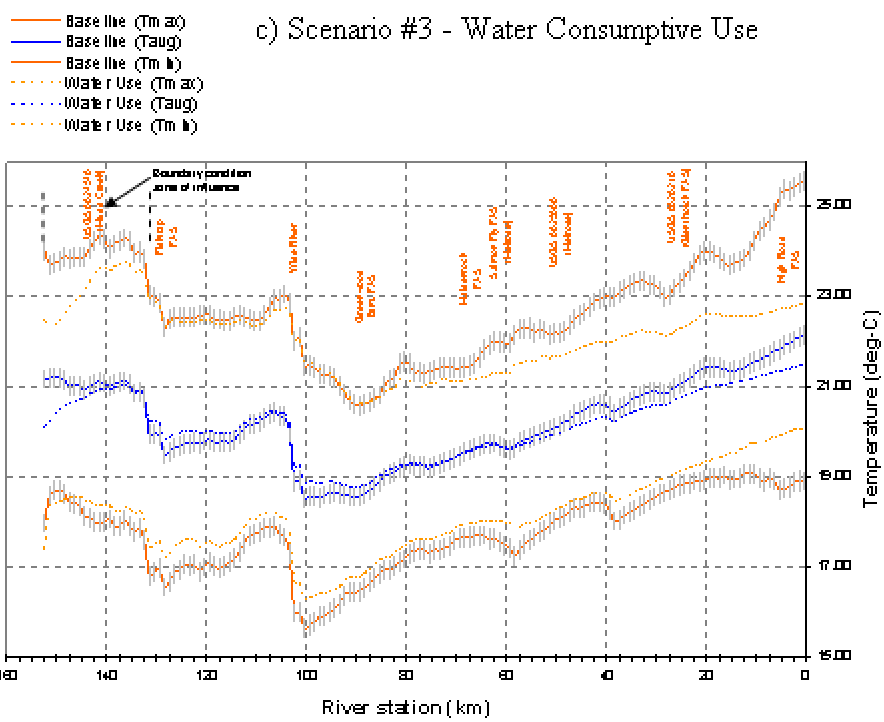
Table D-7. Temperature changes at end of simulation reach resulting from modification of river morphology of the Big Hole River (both SSTEMP and Heatsource v7.0 modeled segments).

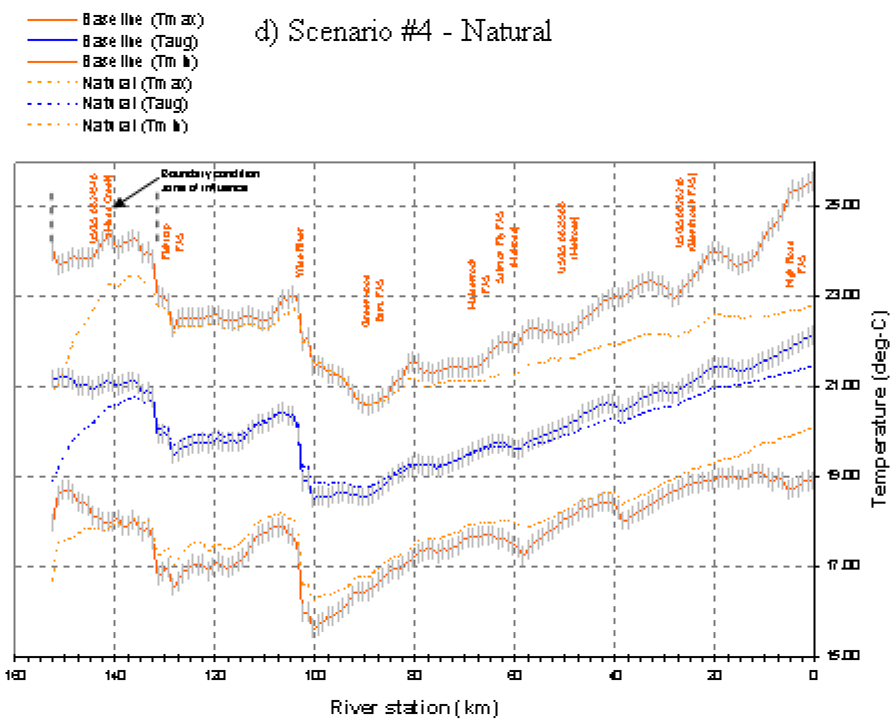
Condition	W-D Ratio	Tmin	Tavg	Tmax
Baseline (94.5-km)	35	17.05	21.18	25.31
Morph Scenario	25	16.34	19.86	23.38
Δ TEMP-Pintlar Cr		-0.71	-1.32	-1.93
Baseline (152.5 km)	>60	18.93	22.17	25.59
Morph Scenario	≤60	18.93	22.16	25.57
Δ TEMP-Twin Br		0.00	-0.01	-0.02
Δ TEMP – all		-0.06	-0.07	-0.07

Figure D-17. Longitudinal temperature effects of management scenarios on the Big Hole River. The grey shaded area represents ±0.23ºC degree variation from that of baseline conditions. Scenarios that deviate outside the 0.23ºC boundary indicate potential impairment.




Baseline (Tmax)
Baseline (Taug)
Baseline (Tmin)
Morphology (Tmax)
Morphology (Taug)
Morphology (Tmin)
b) Scenario #2 - Channel Morphology
Boundary condition zone of influence
Temperature (deg-C)
River station (km)


Baseline (Tmax)
Baseline (Taug)
Baseline (Tmin)
Water Use (Tmax)
Water Use (Taug)
Water Use (Tmin)
c) Scenario #3 - Water Consumptive Use
Boundary condition zone of influence
Temperature (deg-C)
River station (km)


d) Scenario #4 - Natural
Baseline (Tmax)
Baseline (Taug)
Baseline (Tmin)
Natural (Tmax)
Natural (Taug)
Natural (Tmin)
Boundary condition zone of influence
Wise River
Temperature (deg-C)
River station (km)
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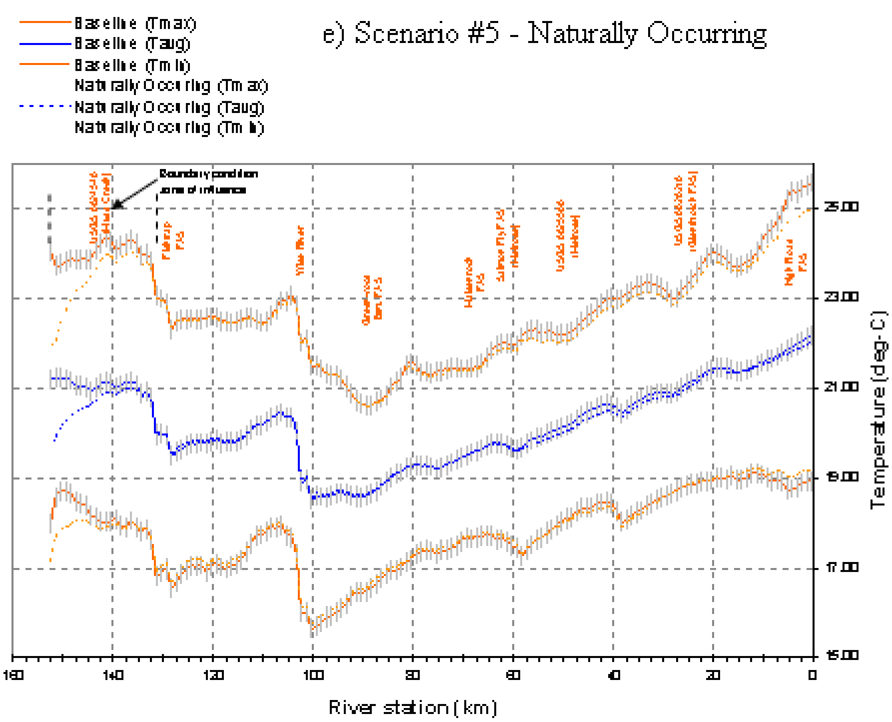
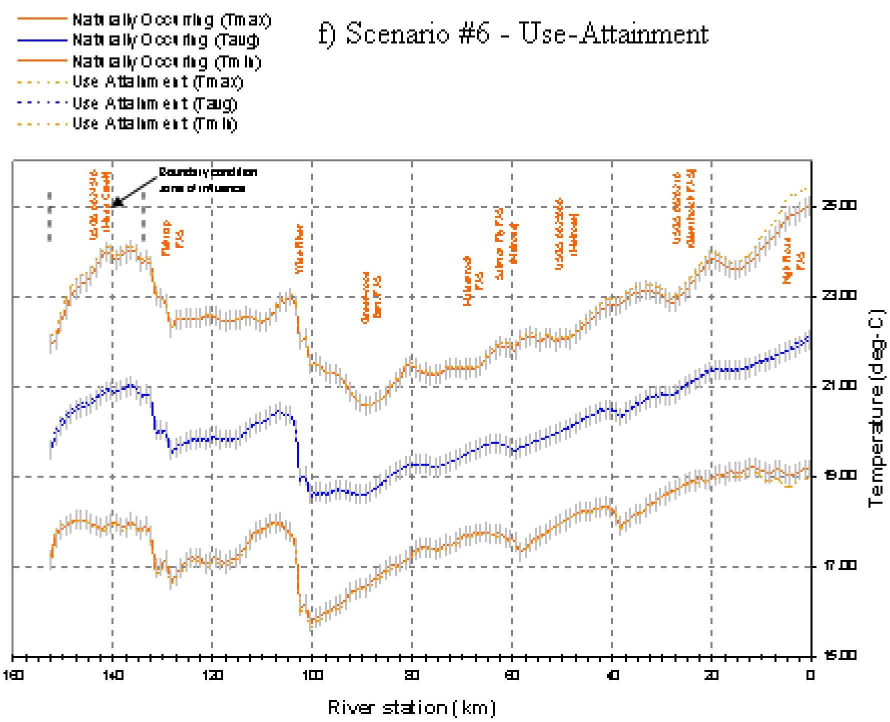
23.00
21.00
19.00
17.00
15.00
160
140
120
100
80
60
40
20
0


e) Scenario #5 - Naturally Occurring
Baseline (Tmax)
Baseline (Taug)
Baseline (Tmin)
Naturally Occurring (Tmax)
Naturally Occurring (Taug)
Naturally Occurring (Tmin)
Boundary condition zone of influence
Wise River
Temperature (deg-C)
River station (km)
25.00
23.00
21.00
19.00
17.00
15.00
160
140
120
100
80
60
40
20
0

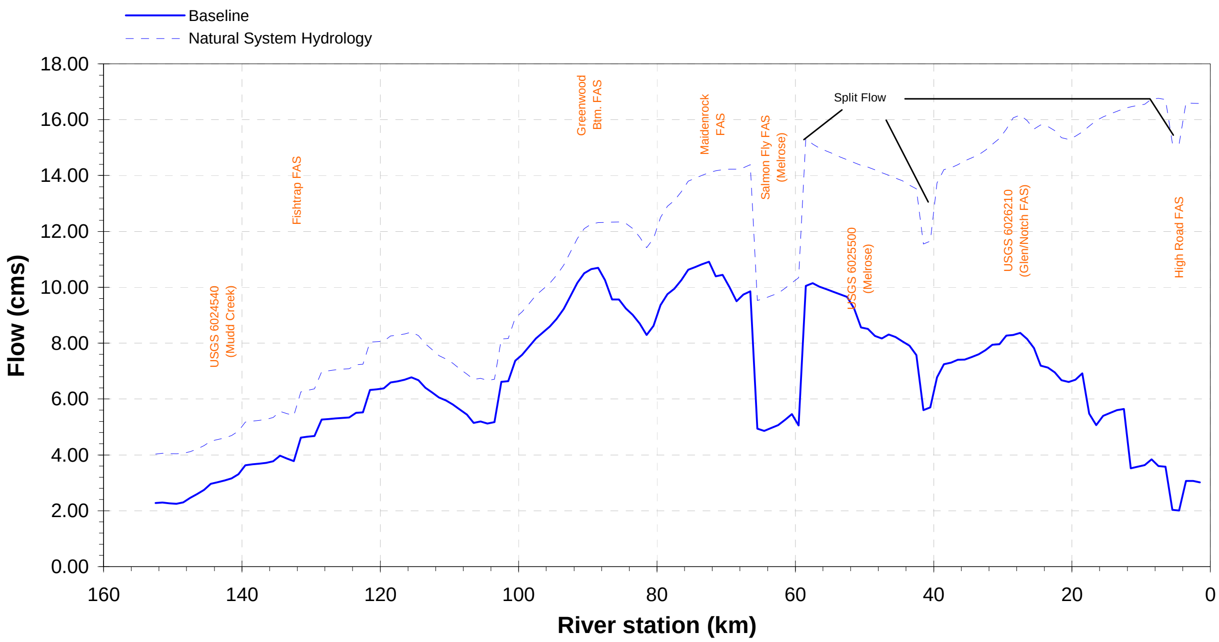


Water Consumptive Use Scenario

The water consumptive use scenario describes the thermal effect of irrigation and domestic water use on the Big Hole River. Although Montana standards do not necessarily apply to consumptive water use, it is important to assess the cumulative effect of these practices on the overall thermal regime of the river. The simple relationship presented by Brown (1969) suggests that large volume streams are less responsive to temperature changes, and conversely, low flow streams will exhibit greater diel fluctuations in stream temperature. The following assumptions were made in the water consumptive use scenario: (1) 1.75 cms (~60 cfs) of natural flow were returned upstream of the detailed study reach along with a corresponding change in temperature, (2) all diversions were removed from the detailed study along with any known return flows, and (3) no additional changes were made.

Overall, it was identified that 13.267 cms (~469 cfs) was diverted from the river during July 25-31 2006 to meet water use requirements in the middle and lower TPA's (**fig. D-18**; see **Appendix-A**). Withdrawl rates are slightly higher than those reported by Wells and Decker-Hess (1981) who indicate up to 9.29 cms (328 cfs) was removed from the river during the summer of 1980, as well as Marvin and Voller (2000) who estimate crop ET alone at 4.9 cms (171 cfs) in the lower basin. With unknown losses in the distribution system, and unaccounted ET in the middle basin, it is very reasonable to assume water withdrawls routinely approximate 9-13 cms in the late summer months. During 2006, all but 0.439 cms were used for agricultural purposes.

Figure D-18. Longitudinal profile of discharge in the watershed as part of the water use scenario. The 1.75 m3/s headwater increase is included in this approximation along with removal of all diversions in the study area.



Model simulations of natural system hydrology indicate that significant changes in temperature occur at the upstream boundary and watershed outlet from irrigation and domestic water withdrawls **(table D-8, fig. D-17c**). 7Davg and 7Dmax are shown to decrease by 0.65 and 2.73°C (1.17 and 4.91°F), while 7Dmin actually increases as due to additional system volume, its associated thermal inertia, and the relative change in the ratio of contribution of groundwater to surface water. Interestingly, water temperatures largely "reset" in the area around Wise River. This phenomena was also observed in other scenarios and is suggestive that basin could be broken into two independent management segments with independent remedial objectives. Clearly, flow augmentation in the Big Hole River is a crucial improvement necessary for modification of in-stream water temperature in the middle and lower TPA's.

Table D-8. Temperature changes at end of simulation reach resulting from modification of consumptive use on the Big Hole River (both SSTEMP and Heatsource v7.0 modeled segments).

Condition	Q (cms)	Tmin	Tavg	Tmax
Baseline (94.5 km)	3.135	17.05	21.18	25.31
Water Scenario	4.885	16.53	20.08	23.63
Δ TEMP-Pintlar Cr	1.75	-0.52	-1.10	-1.68
Baseline (152.5 km)	3.022	18.93	22.17	25.59
Water Scenario	16.579	20.09	21.52	22.86
Δ TEMP-Twin Br		+1.16	-0.65	-2.73
Δ TEMP – all		+0.41	-0.09	-0.66

Natural Condition Scenario

The natural condition scenario reflects the temperature regime that would be expected absent of the influence of man. While this type of scenario is clearly not realistic from a socio-economic implementation standpoint, it does allow for characterizing the extent of departure from natural conditions, and subsequently, the maximum potential improvement in the watershed. It may also be helpful in future resource conservation efforts. For the purpose of this study, natural conditions were defined as the removal of all human influences that affect heat or mass transfer. Natural condition scenario assumptions include the following: (1) reference shade conditions as described in the shade scenario, (2) modified morphology in the 94.5 km reach upstream and constant channel morphology downstream, (3) the same irrigation and consumptive use conditions as in the water consumptive use scenario, and (4) no other associated changes.

Results of the natural condition scenario parallel that of the previous scenario (e.g. water consumptive use) with 7Davg and 7Dmax decreasing by 0.69 to 2.76°C (1.24 and 4.97°F) and 7Dmin increasing (**table D-9**). The marked concurrence between the natural condition and water use scenarios confirm that irrigation and domestic withdrawls are the predominant impairment affecting the Big Hole River; much more so than that of shade and morphology. The natural condition profile is shown in **fig. D-17d**.

Table 9. Temperature changes at end of simulation reach resulting from natural conditions on the Big Hole River (both SSTEMP and Heatsource v7.0 modeled segments).

Condition		Tmin	Tavg	Tmax
Baseline (94.5 km)		17.05	21.18	25.31
Natural Scenario		15.83	18.90	21.97
Δ TEMP-Pintlar Cr		-1.22	-2.28	-3.34
Baseline (152.5 km)		18.93	22.17	25.59
Natural Scenario		20.07	21.48	22.83
Δ TEMP-Twin Br		+1.14	-0.69	-2.76
Δ TEMP – all		+0.30	-0.20	-0.77

Naturally Occurring Scenario (ARM 17.30.602)

The naturally occurring scenario defines water temperature conditions resulting from the implementation of all reasonable land, soil, and water conservation practices (LSWCP), e.g. where stringent best management practices are implemented as outlined in ARM 17.30.602. Essentially, “naturally occurring” establishes the bar for which the allowable 0.23°C (0.5°F) temperature increase is compared to, and effectively determines the impairments status of a water body. Assumptions used in the development of the naturally occurring scenario include the following: (1) identical shade conditions to those described in the shade scenario, (2) modified morphology in the 94.5 km reach upstream, (3) constant channel morphology downstream, (4) a 15 percent (0.5cms) irrigation efficiency improvement in the upper TPA (per DEQ and DNRC estimates), (5) a 15 percent irrigation/domestic water use efficient in the middle and lower TPAs (DEQ estimated), and (6) no other associated changes.

Results of the naturally occurring scenario suggest that 7Davg and 7Dmax would be reduced by 0.13 and 0.59°C (0.23 and 1.06ºF), respectively, while nighttime minimums would increase by 0.26°C (**table**

D-10 and **fig D-17e**). As such, a majority of the river in its current form already meets the State of the Montana temperature standard (e.g. within the 0.23°C allowable increase). Standard violations in 7Dmax do occur in three locations: (1) in the upper reaches as a result of upstream management conditions (river km-152.5-135.5), (2) at river km-55.5 between Melrose and Glen from heavy irrigation and domestic withdrawal, and (3) from river km-10.5 dowstream due to cumulative effects of dewatering. Management activities should be prioritized to address these most impacted sections first, while then worrying about other areas of the river later.

Table D-10. Temperature changes at end of simulation reach resulting from naturally occurring conditions on the Big (both SSTEMP and Heatsource v7.0 modeled segments).

Condition		Tmin	Tavg	Tmax
Baseline (94.5 km)		17.05	21.18	25.31
Naturally Scenario		16.24	19.65	23.06
Δ TEMP-Pintlar Cr		-0.81	-1.53	-2.25
Baseline (152.5 km)		18.93	22.17	25.59
Naturally Scenario		19.19	22.04	25.00
Δ TEMP-Twin Br		+0.26	-0.13	-0.59
Δ TEMP – all		+0.01	-0.09	-0.19

Use Attainment Scenario

A final scenario was developed to illustrate the utility of the Heatsource v7.0 model for future application in the Big Hole River. In this hypothetical scenario, the hypothesis was formulated that 10 percent irrigation efficiency (as opposed to 15 percent, all other factors the same) would be sufficient to meet the State temperature standard. The hypothesis was tested using identical assumptions to that of the naturally occurring scenario, with the exception of the change in flow. Results indicate that for the most part, 10 percent irrigation efficiency would meet allowable increases by State law. Exceedances did occur, however, in the lower watershed, largely disproving the hypothesis (**fig. D-17d**). Therefore, the next step would be to develop a new set of assumptions (perhaps something like a 10 percent efficiency improvement the upper reaches and 15 percent in the lower reaches) as a subsequent test to assess whether water quality standards can be met. Ultimately, the goal would be to identify a suite of BMPs that are agreeable between watershed stakeholders and managers such that the Montana temperature standard is attained and maintained. This, of course, would require cooperative efforts between landowners, watershed groups, managers, modelers, and the general public. For the time being, a watershed-wide 15 percent improvement in flow, along with shading improvement in the upper, middle, and lower TPA's, and morphology improvements in the upper TPA, are recommended to meet the state temperature standard.

CONCLUSION

Water temperature modeling was completed on the Big Hole River using Heatsource v7.0 and SSTEMP such that the mechanistic relationship between in-stream water temperature, stream morphology, riparian conditions, and water management practices could be established for the summer critical low-flow period. Through scenario analysis, it was shown that flow alteration was the most crucial management component influencing water temperature in the basin and that existing water temperatures are 0.59ºC (1.06ºF) warmer than that of naturally occurring conditions. They are 2.76ºC (4.97ºF) higher than natural. Thus the key management recommendation originating from this study is to protect and reestablish in-stream flows to the extent possible.

It was found during the modeling, that much of the middle and lower Big Hole River TPAs already meet the State's temperature criteria. Three areas of concern do exist: (1) in the reaches upstream of Fishtrap Creek/FAS as a result of management conditions in the upper TPA, (2) at river km-55.5 between Melrose and Glen from heavy irrigation and domestic water withdrawal, and (3) from approximately river km-10.5 downstream to Twin Bridges due to cumulative effects of dewatering. It was found that voluntary water conservation of 15 percent would be necessary to meet the state temperature standard in those reaches. Further modeling is recommended such that specific BMPs can be established cooperatively between stakeholders and watershed managers to refine this 15 percent estimate.

Finally, a unique "resetting" condition was identified near the center of the watershed where significant groundwater influx and topographic shading result a thermal buffering of in-stream water temperatures. This functionally separates the upper and middle/lower Big Hole River TMDL planning areas and would allow for future management of the river in two distinct segments.

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APPENDIX E
TEMPERATURE DAILY TMDLS AND INSTANTANEOUS LOADS

A TMDL is the sum of waste load allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources (**Equation E-1**). In addition, the TMDL includes a margin of safety (MOS) that accounts for the uncertainty in the relationship between pollutant loads and the quality of the receiving stream.

Equation E-1. $TMDL = \Sigma WLA + \Sigma LA + MOS.$

Where:

ΣWLA = Waste Load Allocation = Pollutants from NPDES Point Sources
ΣLA = Load Allocation = Pollutants from Nonpoint Sources + Natural Sources
MOS = Margin of Safety

Total maximum daily loads are based on the loading of a pollutant to a water body. Federal Codes indicate that for each thermally listed water body the total maximum daily thermal load cannot be exceeded in order to assure protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife. Such estimates shall take into account the water temperatures, flow rates, seasonal variations, existing sources of heat input, and the dissipative capacity of the identified waters. The following approach for setting numeric temperature TMDLs considers all of the factors listed above.

The numeric thermal daily loads (TMDLs) and instantaneous thermal load (ITLs) presented in this appendix apply to all the temperature impaired waters in Upper and North Fork Big Hole River watersheds. This appendix provides daily and instantaneous heat loading limits for the Big Hole River above Pintlar Creek. All waters in this planning area are classified as A-1. Montana's temperature standard for A-1 classified waters is depicted in **Figure E-1**.

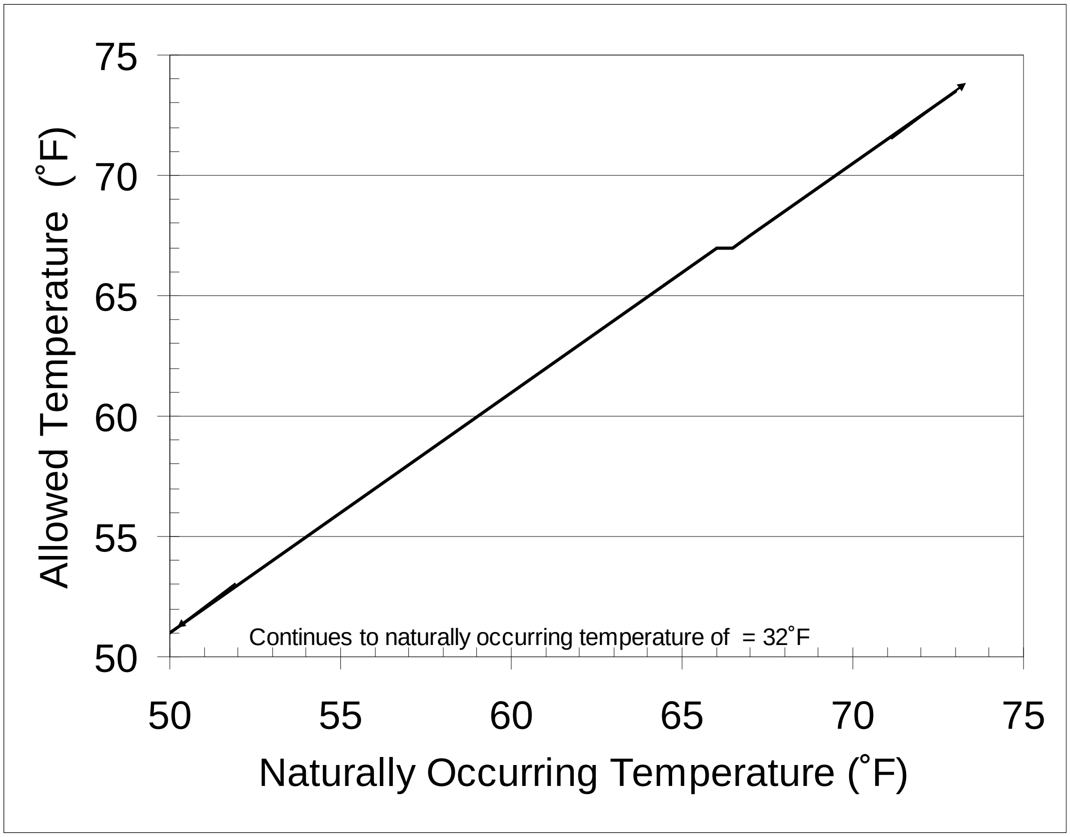

Figure E-1. In-stream Temperatures Allowed by Montana's A-1 Classification Temperature Standard

Daily Thermal Load

The allowed temperature can be calculated using Montana's A-1 classification temperature standards (**Figure E-1**) and using a modeled or estimated naturally occurring daily average temperature. The daily average total maximum load at any location in the water body is provided in **Equation E-2**. The daily allowable loading is expressed as the allowable loading to the liquid form of the water in the stream. This is defined as the kilocalorie increase associated with the warming of the water from 32°F to the temperature that represents compliance with Montana's temperature standard as determined from **Figure E-1**.

Equation E-2

$(\Delta-32)*(Q)*(1.36*10^6) = TMDL$

Where:

Δ = allowed temperatures from **Figure E-1** using daily temperature condition
Q = average daily discharge in cubic feet per second (CFS)
TMDL = daily TMDL in Calories (kilocalories) per day above water's melting point
Conversion factor = 1359209

There are no point sources that increase water temperatures, and therefore, no wasteload allocations for the watershed. The TMDL load allocation for each stream is a combination of the ½ °F allowable loading shared between the human caused sources without reasonable land, soil, and water conservation practices in addition to the naturally occurring loading as defined in state law. Because temperatures are estimated to be naturally above 66 °F at times, one-half degree allowable increase in temperature is used for the TMDL and allocations. See the main document for more information about surrogate allocations, which are more applicable to restoration approaches. The surrogate allocations should meet the daily thermal load. The daily numeric TMDL allocation is equal to the load allocation shared by all human-caused sources without reasonable land, soil and water conservation practices plus the load allocated to naturally occurring temperatures as shown in **Equation E-3**.

Equation E-3

Load Allocation = Allowable Human Sources + Naturally Occurring Thermal Loads

Where:

Naturally Occurring Thermal Loads = (Naturally Occurring Temperature (°F) from Modeling Scenarios -32)*(Discharge (CFS))*($1.36*10^6$)

Allowable Human Sources above naturally occurring conditions = (1/2°F)*($1.36*10^6$)*(Discharge (CFS))

Instantaneous Thermal Load

Because of the dynamic temperature conditions during the course of a day, an instantaneous thermal load (ITL) is also provided for temperature. For temperature, the daily average thermal conditions are not always an effective indicator of impairment to fisheries. The heat of the day is usually the most stressful timeframe for salmonids and char. Also, in high altitudes, thermal impacts that heat during the day may produce advanced cooling conditions during the night so that the daily temperature fluctuations increase greatly with potentially significant negative impacts to fish without much impact on daily average temperature conditions. Therefore, Montana provides an instantaneous thermal load to protect during the hottest timeframes in mid to late afternoon when temperatures are most stressful to the fishery, which is the most sensitive use in reference to thermal conditions.

The instantaneous load is computed by the second. The allowed temperature can be calculated using Montana's A-1 classification temperature standards (**Figure E-1**) and using a modeled or estimated naturally occurring instantaneous temperature. The instantaneous total maximum load (per second) at any location in the water body is provided by **Equation E-4**. The allowable loading over a second is expressed as the allowable loading to the liquid form of the water in the stream. This is defined as the kCal increase associated with the warming of the water from 32°F to the temperature that represents compliance with Montana's temperature standard as determined from **Figure E-1**.

Equation E-4

$(\Delta-32)*(Q)*(15.73)$ = Instantaneous Thermal Load (ITL)

Where:

Δ = allowed temperatures from **Figure E-1** using daily temperature condition
Q = instantaneous discharge in CFS
ITL = Allowed thermal load per second in kilocalories per day above water's melting point
Conversion factor = 15.73

There are no point sources that increase water temperatures, and therefore, no instantaneous wasteload allocations for the watershed. The ITL load allocation for each stream is a combination of the 1/2°F allowable loading shared between the human caused sources without reasonable land, soil and water conservation practices in addition to the naturally occurring loading as defined in state law. Because temperatures are estimated to be naturally above 66 °F at times, one-half degree allowable increase in temperature is used for the TMDL and allocations. See the main document for more information about surrogate allocations, which are more applicable to restoration approaches. The surrogate allocations should meet the ITL. The ITL allocation is equal to the load allocation shared by all human caused sources without reasonable land, soil and water conservation practices plus the load allocated to naturally occurring temperatures as shown in **Equation E-5**.

Equation E-5

Load Allocation = Allowable Human Sources + Naturally Occurring Thermal Loads

Where:

Naturally Occurring Thermal Loads = (Naturally Occurring Temperature (°F) from Modeling Scenarios -32)*(Discharge (CFS))*(15.73)

Allowable Human Sources above naturally occurring conditions = (1/2°F)*(15.73)*(Discharge (CFS))

Margins of Safety, Seasonal Variations and Future Sources

See **Section 7** of the main document for this discussion.

Example Numeric TMDL Application for the Big Hole River above Pintlar Creek

Big Hole River Daily Thermal Load Example Application

Monitoring along with SSTEMP (Stream Segment Temperature Model) and SNTEMP (Stream Network Temperature Model) models were completed on the Big Hole River above Pintlar Creek (Appendicies B, C, D). A SNTEMP model scenario used reference riparian shade conditions throughout the watershed along with an estimated increase of 10cfs to estimate naturally occurring temperatures. Naturally occurring average daily temperature at the Big Hole River's confluence with Pintlar Creek during a hot day of summer 2006 was estimated at 67.3°F using SNTEMP modeling. This temperature is then used to determine the allowable temperature according to **Figure E-1**, Montana's temperature standard. The allowable mean daily temperature is estimated at 67.8°F during the hottest days of the summer. **Equation E-2** from above is used to calculate the Upper Big Hole River TMDL during the hottest days of the summer.

Example:

$(\Delta-32)*(Q)*(1.36*10^6) = TMDL$

Where:

Δ = allowed temperatures from **Figure E-1** using daily temperature condition = **67.8°F**
Q = average daily discharge in cubic feet per second (CFS) = **101cfs**
TMDL = daily TMDL in Calories (kilocalories) per day above water's melting point = **$4.92*10^9$ kilocal/day**

The Upper Big Hole River load allocation to human caused heat sources not addressed by reasonable land, soil and water conservation practices for the TMDL is $6.87*10^7$ kilocalories per day. The remainder of the TMDL is appropriated to naturally occurring thermal load. Since there are no NPDES permits that affect water temperature, there is zero waste load allocation. During warm summer days the mean daily temperature of this site exceeds the average daily TMDL.

Big Hole River Instantaneous Thermal Load

The instantaneous thermal load (ITL) is described as the heat passing a monitoring location per second. The most sensitive timeframe for the fishery occurs during the heat of the day for the hottest period of the year. The same modeling described earlier in this appendix was used to model daily maximum temperatures. The naturally occurring daily maximum temperature at the confluence of the Big Hole River above Pintlar Creek's mouth during one of the hottest days of summer 2006 was estimated at 73.5°F using a SNTEMP model. This temperature is then used to determine the allowable temperature according to **Figure E-1**, Montana's temperature standard. Therefore, the allowable maximum temperature during this timeframe is estimated at 74.0°F during a hot summer day. **Equation E-4** from above is used to calculate the Upper Big Hole River's ITL during one of the hottest days of the summer.

Example:
(Δ-32)*(Q)*(15.73) = Instantaneous Thermal Load (ITL)

Where:
Δ = allowed temperatures from **Figure E-1** using instantaneous temperature condition = **74.0°F**
Q = average daily discharge in cubic feet per second (CFS) = **101cfs**
ITL = Allowed thermal load per second in kilocalories per day above water's melting point = **66,700 kilocal/second**

The Upper Big Hole River's load allocation to human caused heat sources not addressed by reasonable land, soil and water conservation practices for the ITL is 794 kilocalories per second. Since there are no NPDES permits that affect water temperature, there is zero waste load allocation. The remainder of the load allocation for the ITL is apportioned to naturally occurring thermal loading. During the hottest days of the summer the ITL is surpassed at the confluence with Pintlar Creek. This indicates that Montana's temperature standard at this site is not being met during an important timeframe for the most sensitive use.

APPENDIX F
SEDIMENT TOTAL MAXIMUM DAILY LOADS

Overview

A percent reduction approach was used for the TMDLs within this document because there is uncertainty associated with the loads derived from the source assessment, and using the estimated sediment loads creates a rigid perception that the loads are absolutely conclusive. However, because daily loads are a required product of TMDL development and percent reductions are most relevant at an annual scale, loads within this appendix are expressed as daily loads. Daily loads should not be considered absolutely conclusive and may be refined in the future as part of the adaptive management process. The TMDLs may not be feasible at all locations within the watershed but if the allocations are followed, sediment loads are expected to be reduced to a degree that the sediment targets are met and beneficial uses are no longer impaired.

Approach

The average annual sediment loads determined from source assessments were used along with historical flow and suspended sediment data from the Big Hole River to determine average daily sediment loads for all water bodies in the Upper Big Hole TPA. A sediment rating curve was developed using daily flow and suspended solids load data collected from 1960 through 1964 at the USGS gage on the Big Hole River near Melrose, MT (Station 6025500) (**Figure F-1**).

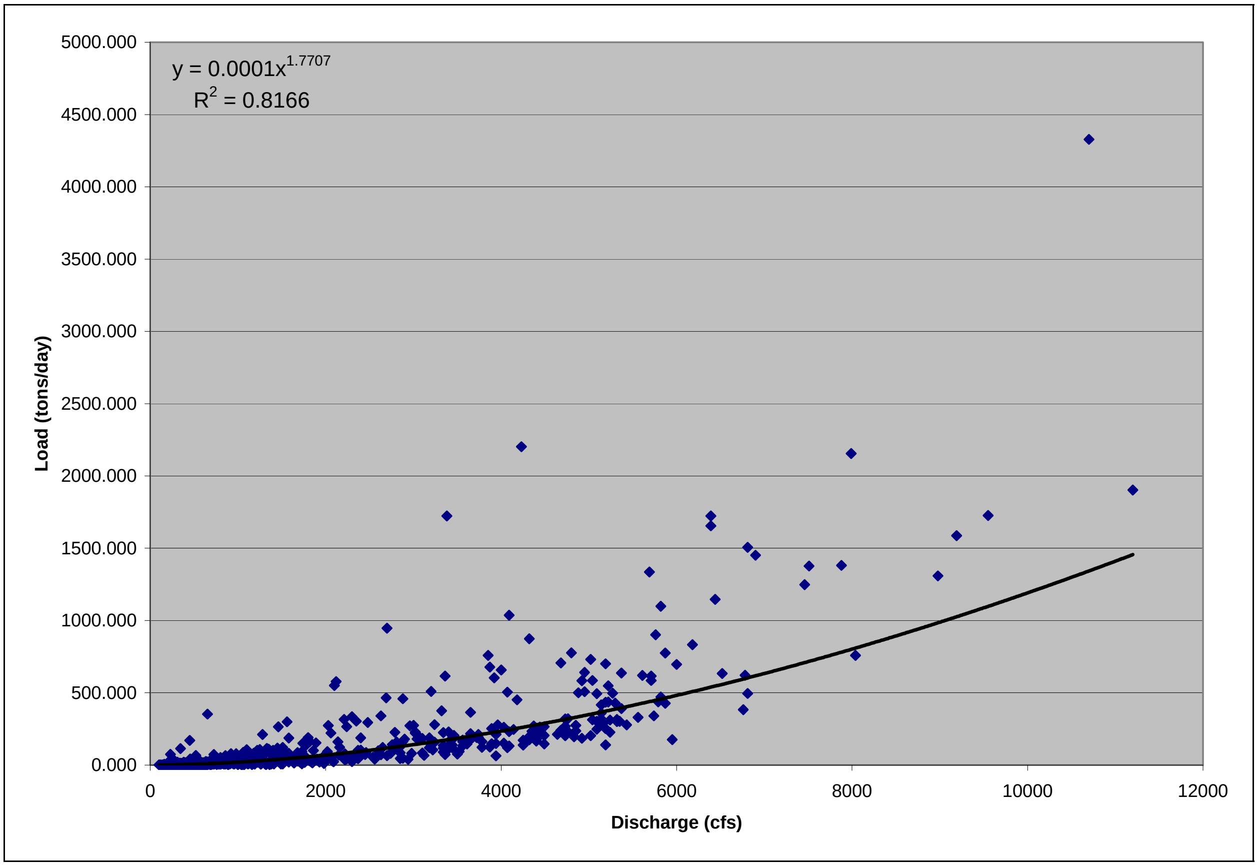

Figure F-1. Sediment Rating Curve for the Big Hole River

The daily mean discharge based on 84 years of record (1923-2007) at the USGS gage was then plugged into the equation for the sediment rating curve to get a daily suspended sediment load. The suspended sediment load is only a fraction of the total load from the source assessment, but provides an approximation of the relationship between sediment and flow in the Big Hole River. Based on the sum of the calculated daily sediment loads, a daily percentage relative to the annual suspended sediment load was calculated for each day. The daily percentages were then applied to the total average annual loads associated with the TMDL calculated from the annual percent reduction in sediment load from **Section 8.3.11** to determine the average daily load. To conserve resources, this appendix contains daily loads for the North Fork of the Big Hole River as an example. As discussed in **Section 8.3.11**, the TMDL for the North Fork of the Big Hole River is a 20 percent reduction in the total average annual sediment load, which is roughly equivalent to an allowed average annual sediment load of 22,914 tons/year. The daily percentages discussed above were then multiplied by the annual load of 22,914 tons to get a daily expression of the North Fork of the Big Hole River TMDL (**Table F-1**). Although the relationship between sediment and flow is likely different within the 303(d) listed tributaries in the Upper and North Fork Big Hole Watersheds than in the Big Hole River, it was used to determine average daily loads because it is the best available data and TMDL implementation activities will not be driven by the daily loads. The daily loads are a composite of the allocations, but as allocations are not feasible on a daily basis, they are not contained within this appendix. If desired, daily allocations may be obtained by applying allocations provided in **Section 8.0** to the daily load. Daily loads for all other TMDLs may be derived by using the daily percentages in **Table F-1,** and the

TMDLs expressed as an average annual load, which are discussed in **Section 8.0** and also provided in **Table F-2**.

Table F-1. Daily TMDL for the North Fork of the Big Hole River.

Month	Day	Daily % of annual load	North Fork Big Hole River TMDL (tons/day)	Month	Day	Daily % of annual load	North Fork Big Hole River TMDL (tons/day)
Jan	1	0.02%	4.8	Feb	17	0.02%	4.8
Jan	2	0.02%	4.8	Feb	18	0.02%	4.9
Jan	3	0.02%	4.8	Feb	19	0.02%	4.9
Jan	4	0.02%	4.8	Feb	20	0.02%	5.0
Jan	5	0.02%	4.7	Feb	21	0.02%	5.0
Jan	6	0.02%	4.6	Feb	22	0.02%	5.1
Jan	7	0.02%	4.6	Feb	23	0.02%	5.1
Jan	8	0.02%	4.8	Feb	24	0.02%	5.1
Jan	9	0.02%	4.7	Feb	25	0.02%	5.1
Jan	10	0.02%	4.7	Feb	26	0.02%	5.3
Jan	11	0.02%	4.6	Feb	27	0.02%	5.3
Jan	12	0.02%	4.7	Feb	28	0.02%	5.3
Jan	13	0.02%	4.7	Feb	29	0.02%	5.1
Jan	14	0.02%	4.8	Mar	1	0.02%	5.3
Jan	15	0.02%	4.7	Mar	2	0.02%	5.2
Jan	16	0.02%	4.7	Mar	3	0.02%	5.2
Jan	17	0.02%	4.6	Mar	4	0.02%	5.3
Jan	18	0.02%	4.5	Mar	5	0.02%	5.2
Jan	19	0.02%	4.5	Mar	6	0.02%	5.4
Jan	20	0.02%	4.5	Mar	7	0.02%	5.6
Jan	21	0.02%	4.5	Mar	8	0.02%	5.7
Jan	22	0.02%	4.5	Mar	9	0.03%	5.8
Jan	23	0.02%	4.5	Mar	10	0.03%	6.0
Jan	24	0.02%	4.5	Mar	11	0.03%	6.2
Jan	25	0.02%	4.5	Mar	12	0.03%	6.5
Jan	26	0.02%	4.5	Mar	13	0.03%	6.7
Jan	27	0.02%	4.5	Mar	14	0.03%	6.9
Jan	28	0.02%	4.5	Mar	15	0.03%	7.0
Jan	29	0.02%	4.4	Mar	16	0.03%	7.5
Jan	30	0.02%	4.5	Mar	17	0.04%	8.1
Jan	31	0.02%	4.6	Mar	18	0.04%	8.3

Table F-1. Daily TMDL for the North Fork of the Big Hole River.

Month	Day	Daily % of annual load	North Fork Big Hole River TMDL (tons/day)	Month	Day	Daily % of annual load	North Fork Big Hole River TMDL (tons/day)
Feb	1	0.02%	4.7	Mar	19	0.04%	8.5
Feb	2	0.02%	4.8	Mar	20	0.04%	8.7
Feb	3	0.02%	4.7	Mar	21	0.04%	9.0
Feb	4	0.02%	4.6	Mar	22	0.04%	9.4
Feb	5	0.02%	4.6	Mar	23	0.04%	9.9
Feb	6	0.02%	4.8	Mar	24	0.04%	10.2
Feb	7	0.02%	4.9	Mar	25	0.05%	10.6
Feb	8	0.02%	5.0	Mar	26	0.05%	11.0
Feb	9	0.02%	5.0	Mar	27	0.05%	11.7
Feb	10	0.02%	5.0	Mar	28	0.06%	13.8
Feb	11	0.02%	4.9	Mar	29	0.07%	15.7
Feb	12	0.02%	4.9	Mar	30	0.07%	16.2
Feb	13	0.02%	4.7	Mar	31	0.07%	16.8
Feb	14	0.02%	4.7	Apr	1	0.08%	17.7
Feb	15	0.02%	4.7	Apr	2	0.08%	18.8
Feb	16	0.02%	4.8	Apr	3	0.08%	19.1
Apr	4	0.09%	21.3	May	21	1.36%	311.2
Apr	5	0.10%	24.0	May	22	1.44%	329.1
Apr	6	0.12%	26.8	May	23	1.46%	335.2
Apr	7	0.13%	30.2	May	24	1.50%	342.9
Apr	8	0.15%	34.1	May	25	1.52%	349.1
Apr	9	0.17%	38.7	May	26	1.58%	363.2
Apr	10	0.18%	41.8	May	27	1.67%	382.3
Apr	11	0.20%	45.5	May	28	1.70%	390.5
Apr	12	0.22%	49.5	May	29	1.78%	406.9
Apr	13	0.23%	52.8	May	30	1.84%	422.0
Apr	14	0.25%	57.7	May	31	1.87%	428.7
Apr	15	0.28%	63.5	Jun	1	1.87%	428.7
Apr	16	0.30%	68.0	Jun	2	1.88%	430.4
Apr	17	0.31%	71.8	Jun	3	1.88%	430.4
Apr	18	0.35%	79.8	Jun	4	1.95%	447.6
Apr	19	0.35%	80.7	Jun	5	1.95%	447.6
Apr	20	0.36%	83.1	Jun	6	2.00%	458.0
Apr	21	0.38%	86.5	Jun	7	2.04%	466.8
Apr	22	0.38%	86.5	Jun	8	2.04%	466.8
Apr	23	0.40%	91.6	Jun	9	2.03%	465.0
Apr	24	0.43%	97.8	Jun	10	1.96%	449.3
Apr	25	0.45%	103.2	Jun	11	1.89%	432.1
Apr	26	0.45%	104.1	Jun	12	1.78%	406.9
Apr	27	0.44%	100.5	Jun	13	1.73%	395.4
Apr	28	0.43%	99.6	Jun	14	1.65%	377.5
Apr	29	0.45%	103.2	Jun	15	1.56%	356.9
Apr	30	0.47%	106.9	Jun	16	1.50%	344.4

Table F-1. Daily TMDL for the North Fork of the Big Hole River.

Month	Day	Daily % of annual load	North Fork Big Hole River TMDL (tons/day)	Month	Day	Daily % of annual load	North Fork Big Hole River TMDL (tons/day)
May	1	0.50%	114.4	Jun	17	1.48%	338.3
May	2	0.51%	116.3	Jun	18	1.43%	327.6
May	3	0.52%	119.3	Jun	19	1.37%	314.1
May	4	0.55%	126.1	Jun	20	1.27%	290.8
May	5	0.58%	132.2	Jun	21	1.21%	278.0
May	6	0.60%	137.3	Jun	22	1.15%	262.7
May	7	0.62%	142.5	Jun	23	1.06%	242.5
May	8	0.67%	154.3	Jun	24	0.97%	221.7
May	9	0.73%	166.5	Jun	25	0.89%	202.9
May	10	0.76%	174.4	Jun	26	0.82%	187.3
May	11	0.79%	180.2	Jun	27	0.77%	175.6
May	12	0.80%	183.7	Jun	28	0.72%	165.4
May	13	0.83%	190.8	Jun	29	0.66%	151.1
May	14	0.89%	202.9	Jun	30	0.62%	141.5
May	15	0.93%	214.1	Jul	1	0.56%	128.1
May	16	1.01%	230.7	Jul	2	0.52%	118.3
May	17	1.08%	247.8	Jul	3	0.47%	107.8
May	18	1.15%	262.7	Jul	4	0.43%	99.6
May	19	1.18%	271.0	Jul	5	0.41%	93.4
May	20	1.26%	289.4	Jul	6	0.37%	84.0
Jul	7	0.33%	75.8	Aug	22	0.02%	5.4
Jul	8	0.31%	71.1	Aug	23	0.02%	5.4
Jul	9	0.29%	67.2	Aug	24	0.02%	5.6
Jul	10	0.28%	63.5	Aug	25	0.02%	5.5
Jul	11	0.26%	59.8	Aug	26	0.02%	5.4
Jul	12	0.25%	57.7	Aug	27	0.02%	5.2
Jul	13	0.23%	52.1	Aug	28	0.02%	5.0
Jul	14	0.21%	47.5	Aug	29	0.02%	4.8
Jul	15	0.19%	42.4	Aug	30	0.02%	4.6
Jul	16	0.17%	38.1	Aug	31	0.02%	4.6
Jul	17	0.15%	34.7	Sep	1	0.02%	4.5
Jul	18	0.14%	32.4	Sep	2	0.02%	4.4
Jul	19	0.13%	30.2	Sep	3	0.02%	4.4
Jul	20	0.13%	29.3	Sep	4	0.02%	4.3
Jul	21	0.12%	27.5	Sep	5	0.02%	4.2
Jul	22	0.11%	25.9	Sep	6	0.02%	4.2
Jul	23	0.10%	24.0	Sep	7	0.02%	4.2
Jul	24	0.10%	21.8	Sep	8	0.02%	4.3
Jul	25	0.09%	20.1	Sep	9	0.02%	4.6
Jul	26	0.08%	19.0	Sep	10	0.02%	4.5
Jul	27	0.08%	18.0	Sep	11	0.02%	4.5
Jul	28	0.07%	16.9	Sep	12	0.02%	4.6
Jul	29	0.07%	16.0	Sep	13	0.02%	4.7
Jul	30	0.07%	15.5	Sep	14	0.02%	4.7
Jul	31	0.07%	15.5	Sep	15	0.02%	4.7

Table F-1. Daily TMDL for the North Fork of the Big Hole River.

Month	Day	Daily % of annual load	North Fork Big Hole River TMDL (tons/day)	Month	Day	Daily % of annual load	North Fork Big Hole River TMDL (tons/day)
Aug	1	0.06%	14.8	Sep	16	0.02%	4.7
Aug	2	0.06%	13.9	Sep	17	0.02%	4.8
Aug	3	0.06%	13.3	Sep	18	0.02%	5.0
Aug	4	0.05%	12.6	Sep	19	0.02%	5.2
Aug	5	0.05%	11.8	Sep	20	0.02%	5.6
Aug	6	0.05%	11.0	Sep	21	0.03%	5.8
Aug	7	0.04%	10.2	Sep	22	0.03%	5.9
Aug	8	0.04%	9.3	Sep	23	0.03%	5.9
Aug	9	0.04%	8.6	Sep	24	0.03%	6.0
Aug	10	0.04%	8.1	Sep	25	0.03%	5.9
Aug	11	0.03%	7.7	Sep	26	0.03%	6.0
Aug	12	0.03%	7.5	Sep	27	0.03%	6.1
Aug	13	0.03%	7.2	Sep	28	0.03%	6.2
Aug	14	0.03%	6.9	Sep	29	0.03%	6.5
Aug	15	0.03%	6.7	Sep	30	0.03%	6.6
Aug	16	0.03%	6.5	Oct	1	0.03%	6.8
Aug	17	0.03%	6.2	Oct	2	0.03%	6.8
Aug	18	0.03%	5.9	Oct	3	0.03%	7.0
Aug	19	0.02%	5.7	Oct	4	0.03%	7.2
Aug	20	0.02%	5.5	Oct	5	0.03%	7.3
Aug	21	0.02%	5.4	Oct	6	0.03%	7.4
Oct	7	0.03%	7.5	Nov	22	0.03%	7.4
Oct	8	0.03%	7.6	Nov	23	0.03%	7.1
Oct	9	0.03%	7.6	Nov	24	0.03%	7.2
Oct	10	0.03%	7.8	Nov	25	0.03%	7.7
Oct	11	0.03%	7.9	Nov	26	0.03%	7.6
Oct	12	0.04%	8.1	Nov	27	0.03%	7.2
Oct	13	0.04%	8.2	Nov	28	0.03%	6.9
Oct	14	0.04%	8.4	Nov	29	0.03%	6.9
Oct	15	0.04%	8.6	Nov	30	0.03%	6.7
Oct	16	0.04%	8.9	Dec	1	0.03%	6.9
Oct	17	0.04%	8.9	Dec	2	0.03%	7.2
Oct	18	0.04%	8.9	Dec	3	0.03%	7.1
Oct	19	0.04%	8.8	Dec	4	0.03%	7.0
Oct	20	0.04%	8.8	Dec	5	0.03%	6.5
Oct	21	0.04%	9.0	Dec	6	0.03%	6.2
Oct	22	0.04%	9.3	Dec	7	0.03%	6.0
Oct	23	0.04%	9.5	Dec	8	0.02%	5.7
Oct	24	0.04%	9.6	Dec	9	0.03%	5.8
Oct	25	0.04%	9.5	Dec	10	0.03%	5.9
Oct	26	0.04%	9.7	Dec	11	0.03%	6.0
Oct	27	0.04%	9.8	Dec	12	0.03%	6.0
Oct	28	0.04%	9.7	Dec	13	0.03%	5.8
Oct	29	0.04%	9.6	Dec	14	0.03%	5.7
Oct	30	0.04%	9.5	Dec	15	0.03%	5.7
Oct	31	0.04%	9.5	Dec	16	0.02%	5.6

Table F-1. Daily TMDL for the North Fork of the Big Hole River.

Month	Day	Daily % of annual load	North Fork Big Hole River TMDL (tons/day)	Month	Day	Daily % of annual load	North Fork Big Hole River TMDL (tons/day)
Nov	1	0.04%	9.5	Dec	17	0.02%	5.5
Nov	2	0.04%	9.4	Dec	18	0.02%	5.2
Nov	3	0.04%	9.5	Dec	19	0.02%	5.1
Nov	4	0.04%	9.8	Dec	20	0.02%	5.1
Nov	5	0.04%	9.7	Dec	21	0.02%	5.2
Nov	6	0.04%	9.8	Dec	22	0.02%	5.2
Nov	7	0.04%	9.8	Dec	23	0.02%	5.4
Nov	8	0.04%	9.9	Dec	24	0.02%	5.4
Nov	9	0.04%	9.9	Dec	25	0.02%	5.2
Nov	10	0.04%	9.5	Dec	26	0.02%	5.1
Nov	11	0.04%	9.3	Dec	27	0.02%	5.3
Nov	12	0.04%	9.2	Dec	28	0.02%	5.2
Nov	13	0.04%	9.0	Dec	29	0.02%	4.9
Nov	14	0.04%	8.9	Dec	30	0.02%	4.9
Nov	15	0.04%	8.9	Dec	31	0.02%	4.9
Nov	16	0.04%	8.5				
Nov	17	0.04%	8.6				
Nov	18	0.04%	8.6				
Nov	19	0.04%	8.3				
Nov	20	0.03%	7.7				
Nov	21	0.03%	7.6				

Table F-2. Average Annual Sediment Loads

Stream Segment	**Water Body #**	**TMDL expressed as average annual load (tons/year)**
Big Hole River, above Pintlar Creek	MT41D001-030	97,963
North Fork Big Hole River, headwaters to mouth (Big Hole River)	MT41D004-010	22,914
Mussigbrod Creek, headwaters to mouth (North Fork Big Hole River)	MT41D004-020	1,835
Johnson Creek, headwaters to mouth (North Fork Big Hole River)	MT41D004-030	1,994
Tie Creek, headwaters to mouth (North Fork Big Hole River)	MT41D004-060	1,452
Trail Creek, Headwaters to Joseph Creek	MT41D004-070	1,612
Trail Creek, Joseph Creek to mouth (North Fork Big Hole River)	MT41D004-080	4,748
Joseph Creek, headwaters to mouth (Trail Creek-North Fork Big Hole River)	MT41D004-090	802
Ruby Creek, headwaters to mouth (North Fork Big Hole River)	MT41D004-100	4,312
Swamp Creek, headwaters to mouth (Big Hole River)	MT41D004-110	4,252
Rock Creek, headwaters to mouth (Big Hole River)	MT41D004-120	4,888
Miner Creek, headwaters to mouth (Big Hole River)	MT41D004-140	3,069
Governor Creek, headwaters to mouth (Big Hole River-South of Jackson)	MT41D004-150	15,131
Pine Creek, headwaters to mouth (Andrus Creek-Governor Creek)	MT41D004-160	519
Fox Creek, headwaters to mouth (Governor Creek)	MT41D004-170	1,628
Steel Creek, headwaters to mouth (Big Hole River)	MT41D004-190	5,333
Francis Creek, headwaters to mouth (Steel Creek) T3S R15W	MT41D004-200	1,755
McVey Creek, headwaters to mouth (Big Hole River) T1S R15W	MT41D004-210	1,210
Doolittle Creek, tributary to the Big Hole River T1S, R14W	MT41D004-220	956

APPENDIX G
SEDIMENT CONTRIBUTION FROM ROAD EROSION

Approach

Sediment delivery from roadways was estimated using WARSEM, a Microsoft Access based model developed for and used by the State of Washington Department of Natural Resources for assessing sediment production and delivery to streams from roads under its jurisdiction. WARSEM is an empirical model and estimates sediment production and delivery based on road surfacing, road use, underlying geology, precipitation, road age, road gradient, road prism geometry (including road configuration and ditch geometry), cut slope cover, and other factors (Dube' et al 2004).

Data Sources

For a Level 3 assessment, defined in the WARSEM documentation as "detailed assessment and scenario playing," the following parameters are required and must be field verified: Road location, surfacing, geology, segment length, road width, road gradient, delivery type, road configuration and prism geometry, cut slope height, cut slope cover, and ditch width. Traffic level is a parameter that is required, but may be estimated and need not be field verified. Three parameters are optional: Ditch condition, BMPs, and road age.

Data was collected and field verified for all but two of the required parameters: Road age and geology. Road age was estimated as per the model requirements. Budget constraints did not permit sending a geologist to the field to verify these data for each sampled road segment, but, given the coarse graduation of the effect of the geology parameter on model results (high, med, and low erosion classes), the greater accuracy of our method of assigning geology data to a sample location versus that assumed by the model (GIS overlay of specific lat/long positions, as opposed to general location by public land survey section number) we do not believe that this adversely affects the validity of the results.

WARSEM uses internal datasets for its rainfall and (non-field-verified) geology parameters. The user does not enter these data directly; they are derived based on the location of the sample site. These internal datasets are only defined for Washington State. We modified the WARSEM model by adding Montana specific datasets for these parameters. The geology erosion factor parameter was derived from data obtained from GIS coverage of the USGS 1:500K geology map of Montana. Appropriate values were determined based on a table of values for a variety of geologies (Dube' et al. 2004). The rainfall factor parameter was derived from PRISM precipitation data obtained from the Spatial Climate Analysis Service at Oregon State University. The PRISM data set gives mean monthly and annual precipitation levels for the United States at a resolution of 4 kilometers.

To extrapolate the WARSEM model results from the sampled road segments to the watershed as a whole, comprehensive datasets representing the locations of roads and streams were needed. We used GIS coverage of 2000 TIGER road data for road locations and the national hydrography dataset (NHD) for stream locations. We supplemented the sparse coverage of local roads in the TIGER data by digitizing additional road locations from 1:24,000 scale digital orthophotos.

Methods

Field data collection

The WARSEM assumes that roads greater than 200 feet from a stream do not deliver sediment to that stream unless a roadside ditch or gully is present to convey flow from the road to the stream or a point within 200 feet of the stream. Buffering the stream layer by 200 feet and intersecting this buffer with the roads data using GIS methods, identified potential sample locations for collecting field data as well as road segments to which the model results would be extrapolated. The field-sampling plan for the road data allocated the samples to be taken according to attributes which could be readily identified from GIS databases and which corresponded to the WARSEM parameters with the greatest effect on model results. Potential sample locations were stratified according to:

- Road type from the TIGER data. This was assumed to be an indicator of road surface, tread width, and traffic use.
- Ownership (USFS vs. other). This was assumed an indication of road surface, slope, traffic use, and management practices.
- STATSGO soil unit. This was assumed to be indicative of cut slope and ditch condition. It offers a finer division than the gross geology of the parent material on which the road was constructed.

As the variability of these attributes over the sample locations could not be predicted, sample locations were first chosen proportionally in accordance to the frequency of each combination of the values of those attributes, and the proportions were then adjusted to ensure that the more rare combinations of these attributes would have a sufficient number of samples taken to be statistically representative. As implemented, budget considerations resulted in fewer than the recommended number of samples being taken, and those were targeted toward the permutations that represented the greatest proportion of the roads in the watershed. Of the 47 permutations of ownership, road type, and soil type found in the basin, the 44 sampled locations captured 14. Those 14 categories encompass 82% of the roads (by length) in the Big Hole watershed. A more complete description of the sampling methodology can be found in the Road Sediment Sampling Plan.

Field crews were trained in collecting road data according to the assumptions and specifications of the WARSEM model and provided the appropriate equipment (clinometer, measuring tape, GPS, etc) to make accurate measurements. Locations of road sampling locations are shown in **Figure G-1.**

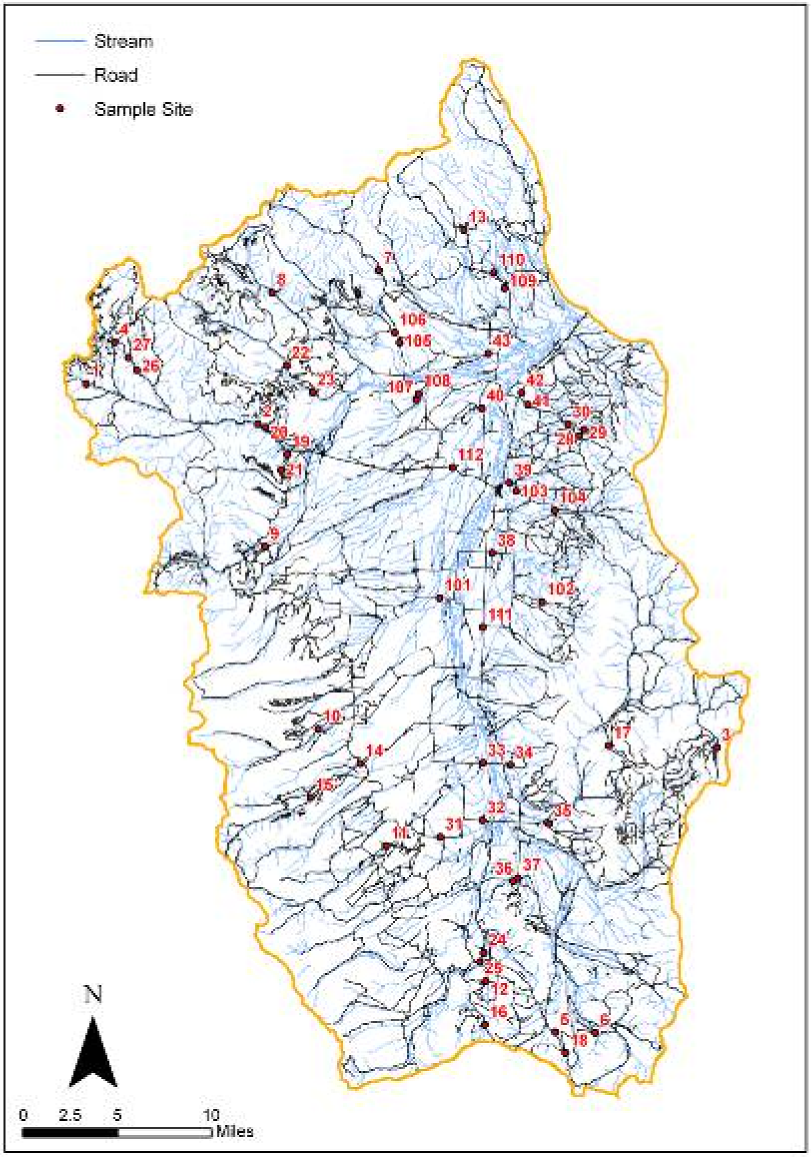

Figure G-1. Road sediment field sampling locations

When field crews noted existing BMPs at the sampled sites, the effect of the BMPs was included in the modeling of sample sites in the WARSEM by applying the appropriate model inputs to describe the observed BMPs. For example, rubber water diverters may have shortened the contributing segment length. If road surface BMPs were encountered model inputs reflected the existing field conditions. As a result, the existing BMPs were taken into account and were extrapolated throughout the watershed.

Model run and extrapolation

The WARSEM was run using the collected and derived input data, resulting in a predicted sediment delivery in tons/yr for each field sample segment. Extrapolation to the entire watershed was based on three parameters – lumped road class, road/stream orientation, and geology erosion factor. Each road segment (within 200 feet of an NHD stream) in the GIS was assigned values for each of these categories. Extrapolation parameters were selected based on their relevance to road sediment production in the watershed. Based on an initial extrapolation attempt it was discovered that road class was not as important a factor as originally anticipated. Sediment production rates were nearly the same for 4x4, local, and ranch roads, but significantly different for highways. This makes sense in the rural Big Hole because essentially all non-highway road segments are dirt roads. To simplify the extrapolation process and reduce the number of extrapolation factors requiring data, the road class category was converted to a lumped road class, which includes only 2 classes – 4x4/local/ranch (4LR), and highway (HWY). The road/stream orientation category consisted of the following segment types: crossing (Xing) for road segments that cross streams, and parallel (Para) for road segments that are adjacent to streams but do not cross them. Geology erosion factor within the upper Big Hole was classified either low (G1) or high (G5) according to the WARSEM standards.

Eight extrapolation classes resulted from the combination of these 3 parameters: 4LRXingG1, 4LRXingG5, HWYXingG1, HWYXingG5, 4LRParaG1, 4LRParaG5, HWYParaG1, HWYParaG5. The surveyed sites were broken down by extrapolation class and WARSEM was used to predict sediment delivery from each of the surveyed sites. An extrapolation factor was developed for each extrapolation class based on WARSEM results and the GIS.

$$ExtrapFactor = \frac{\sum_{i=1}^{n}\left[\frac{TS_i}{LGIS_i}\right]}{n} \qquad (1)$$

Where: *TS = total sediment delivery predicted by WARSEM for a given sample site (tons/year)*
LGIS = length of road within 200 ft of a stream at a given sample site as predicted by the GIS (ft)
n = number of sample sites for the extrapolation class in question

Adequate sample site data were not available to develop extrapolation factors for the following extrapolation classes: HWYParaG1, and HWYParaG5. To overcome this data deficit, the following assumptions were made to develop a complete set of extrapolation parameters.

The HWYParaG1, and HWYParaG5 factors were developed by scaling (multiplying) the HWYXingG1, HWYXingG5 factors by the extrapolation factor ratios 4LRXingG1/4LRParaG1 and 4LRXingG5/4LRParaG5 respectively. These ratios were found to be

4LRXingG1 / 4LRParaG1 = 0.881543662000298 and
4LRXingG5 / 4LRParaG5 = 0.0661288010471528 .

The missing extrapolation factors were then determined by the following equations:

HWYParaG1 = 0.881543662000298 * HWYXingG1 and
HWYParaG5 = 0.0661288010471528 * HWYXingG5

The resulting units of the extrapolation factor are tons of sediment per year per foot of GIS measured length. Prediction of the sediment delivered from all roads in the GIS was accomplished by multiplying the length of a given road segment in the GIS by the extrapolation factor for the matching extrapolation class.

BMP Application Scenarios

The TMDL process requires the comparison of existing loads to natural background levels and to levels where reasonable land, soil, and water conservation practices are in place. Because roads do not naturally exist, the standard practice has been to compare existing loads to loads that might be expected following the application of specific sediment reducing BMPs. The WARSEM allows users to evaluate the potential effects of many different road BMPs. The following BMP scenarios were modeled: installing silt fences in ditches at all crossings, installing other ditch BMPs at crossings, returning rutted roads to original condition, and applying length reducing BMPs at crossings.

> *Silt Fences at All Crossings* - This is a prediction of sediment loads if silt fences or hay bales were installed at all road/stream *crossings*. Based on existing research, WARSEM assumes that using these BMPs can result in trap efficiencies of 25%. Therefore, predicted deliveries (existing conditions) were reduced by 25%.
>
> *Other Ditch BMPs at All Crossings* - This is a prediction of sediment loads if alternates to silt fence such as slash, rock weirs, or vegetation were installed in ditches at all road/stream *crossings*. Based on best professional judgment and extensive field observations, the project team feels that these measures are less effective at reducing sediment delivery, but longer term/lower maintenance solutions than silt fence and hay bales. Therefore, predicted deliveries (existing conditions) were reduced by 15%.
>
> *Restoring Rutted Road Surfaces to Original Condition* – This is a prediction of sediment loads if the surfaces of all contributing road segments classified as rutted are upgraded to their initial condition. For example, rutted native surfaces are upgraded to native surfaces. All reductions from altering road surface conditions can be based on the following matrix (**Table G-1**) that was developed from WARSEM road surface parameters. The numbers in the matrix are multipliers used to determine the resulting sediment delivery if the road surface is changed from the condition listed at the left side of the table to the condition listed at the top of the table. Due to feasibility, however, the only investigated road surface BMP was restoring rutted road surfaces to their original condition.

Table G-1. Road surface sediment reduction multiplier matrix

			TO						
			native/ruts	native	grassed	pit run	gravel/ruts	gravel	asphalt
			2	1	0.5	0.5	0.4	0.2	0.03
FROM	native/ruts	2	1	0.5	0.25	0.25	0.2	0.1	0.015
	native	1	x	1	0.5	0.5	0.4	0.2	0.03
	grassed	0.5	x	x	1	1	0.8	0.4	0.06
	pit run	0.5	x	x	x	1	0.8	0.4	0.06
	gravel/ruts	0.4	x	x	x	x	1	0.5	0.075
	gravel	0.2	x	x	x	x	x	1	0.15
	asphalt	0.03	x	x	x	x	x	x	1

Apply Length Reducing BMPs at Crossings - This is a prediction of sediment loads if length reducing BMPs are applied to all crossing segments. Because BMPs must be selected on a site-by-site basis, no specific length reducing BMP was applied. Rather, the assumption was that one or more length reducing BMPs would be applied in a manner such that the length of the contributing segment would be reduced to 500 ft per crossing (USFS roads) or 100 ft per crossing (for all other roads). It is important to note that in reality, BMPs may not be applicable at some sites due to specific constraints, and the actual result of applying BMPs will vary from site to site. The lengths of 500 ft and 100 ft were intended to represent reasonable average contributing lengths resulting from BMP installation at crossings and are not formal goals. Forest Service roads were treated differently from those owned by other agencies or private individuals to reflect the effect that varying topography, road management policy, and economic feasibility between owner categories.

Results

Table G-2 contains existing sediment loads from unpaved roads as well as potential reductions associated with the various BMP scenarios based on the WARSEM as extrapolated to the 6^{th} code HUC subwatersheds.

Table G-2. Existing and potential sediment loads from unpaved roads by 6th code HUC.

Road Sediment Modeling And "What If" Scenario Summary Table	*Existing Conditions*	*Settling Basins @ All Crossings*	*Silt Fences @ All Crossings*	*Upgrade All Contributing Road Surfaces to Gravel*	*Upgrade All Contributing Road Surfaces One Level*	*Upgrade All Contributing Road Surfaces One Level (no Paving)*	*Repair All Rutted Contributing Road Surfaces to Original Condition*	*Apply Length Reducing BMPS at Crossings to Reduce Contributing Length to 500 ft for USFS Roads and 100 ft for OTHER Roads*
Sub Watershed Name	*(Ton/yr)*	*(Ton/yr)*	*(Ton/yr)*	*(Ton/yr)*	*(Ton/yr)*	*(Ton/yr)*	*(Ton/yr)*	*(Ton/yr)*
Andrus Creek	86.51	15.60	65.65	21.15	41.73	41.73	86.43	61.25
Berry Creek	1.31	0.28	1.01	0.33	0.63	0.63	1.31	1.09
Big Swamp Creek	32.53	6.59	24.90	7.32	15.99	15.99	32.48	29.11
Big Hole River-Big Swamp Creek	90.67	17.61	69.18	22.57	43.69	43.69	90.57	56.54
Big Hole River-McVey Homestead	66.62	14.97	51.43	17.05	32.09	32.09	66.51	42.21
Big Hole River-Saginaw Creek	87.24	15.46	66.13	21.35	42.05	42.05	87.16	66.67
Big Hole River-Spring Creek	86.00	16.51	65.56	21.34	41.44	41.44	85.90	53.61
Big Hole River-Squaw Creek	45.50	8.60	34.65	11.22	21.95	21.95	45.45	28.08
Big Hole River-Wisdom	91.37	16.03	69.21	22.34	44.04	44.04	91.29	57.37
Big Lake Creek	42.61	9.40	32.84	10.86	20.52	20.52	42.54	29.26
Bull Creek	67.63	11.24	51.04	16.31	32.63	32.63	67.58	44.44
Doolittle Creek	76.92	14.22	58.48	18.98	37.07	37.07	76.84	61.58
Englejard Creek	59.53	10.53	45.12	14.57	28.69	28.69	59.47	45.52
Fox Creek	27.28	5.96	21.01	6.88	13.16	13.16	27.24	21.32
Francis Creek	71.05	11.84	53.63	17.24	34.24	34.24	71.00	51.12
Headwaters Big Hole River	43.49	9.19	33.40	11.00	20.95	20.95	43.43	35.04
Howell Creek	29.86	4.78	22.49	7.05	14.46	14.46	29.84	19.10
Johnson Creek	66.82	11.77	50.63	16.05	32.32	32.32	66.76	54.43
Joseph Creek	5.36	1.60	4.26	1.46	2.58	2.58	5.34	4.55
Little Lake Creek	47.90	8.41	36.28	10.78	23.41	23.41	47.86	39.66
Lower Governor Creek	100.49	19.97	76.81	25.06	48.44	48.44	100.36	61.76
Lower Rock Creek	29.10	7.48	22.75	7.66	14.01	14.01	29.04	18.85
Lower Trail Creek	62.03	12.94	47.59	30.79	40.35	40.35	61.96	39.05
Lower Warm Springs Creek	109.22	19.22	82.75	26.69	52.65	52.65	109.13	77.70
May Creek	1.67	0.28	1.27	0.41	0.81	0.81	1.67	1.37
McVey Creek	45.66	7.53	34.44	11.06	22.00	22.00	45.63	33.46
Miner Creek	40.14	8.19	30.74	10.07	19.34	19.34	40.09	30.16
Mussigbrod Creek	26.51	7.21	20.83	7.07	12.76	12.76	26.44	18.68
North Fork Bighole River	82.98	17.39	63.69	20.27	40.22	40.22	82.85	50.14
Old Tim Creek	37.72	7.04	28.70	7.84	18.78	18.78	37.65	36.01
Pine Creek	5.20	2.29	4.35	1.59	2.50	2.50	5.17	4.58
Pintler Creek	49.02	7.83	36.90	11.81	23.63	23.63	48.99	31.03
Plimpton Creek	48.77	8.56	36.95	11.45	23.71	23.71	48.72	30.65
Ruby Creek	109.87	24.84	84.86	28.16	52.92	52.92	109.68	89.17
Schulz creek	1.63	0.70	1.35	0.49	0.78	0.78	1.62	1.43
Stanley Creek	22.78	3.60	17.14	5.48	10.98	10.98	22.76	13.59
Steel Creek	99.65	17.11	75.37	24.24	48.03	48.03	99.57	67.85
Swamp Creek	67.33	13.83	51.59	16.93	32.43	32.43	67.24	44.84
Tie Creek	40.01	7.73	30.51	9.95	19.28	19.28	39.96	32.82
Upper Governor Creek	53.55	9.26	40.52	12.99	25.84	25.84	53.50	39.13
Upper Rock Creek	82.53	15.01	62.67	20.31	39.77	39.77	82.45	56.79
Upper Trail Creek	31.81	11.20	25.75	9.03	15.31	15.31	31.68	26.97
Upper Warm Springs Creek	16.90	3.16	12.86	3.38	8.45	8.45	16.87	16.90
West Fork Ruby Creek	53.20	10.98	40.78	13.39	25.63	25.63	53.13	38.58
Grand Total	2343.95	453.96	1788.07	592.00	1142.27	1142.27	2341.19	1663.45

APPENDIX H
SEDIMENT CONTRIBUTION FROM STREAMBANK EROSION

Approach
Application of the BEHI method (Rosgen 2001) allowed estimation of sediment delivery from stream banks. This methodology predicts stream erosion rate to sampled stream banks, creating an extrapolation factor from the results, and applying this extrapolation factor to the total length of streams in each 6th code HUC sub-watershed (as modified to break out 303d listed streams). The BEHI method is an empirical technique based on bank erosion rate data recorded in the Lamar River watershed of Yellowstone National Park and a variety of streams in the Colorado Front Range. Rosgen (2001) found a statistically significant relationship between the BEHI rating and bank erosion rate in the absence of any data representing the near bank shear stress. The method allows for prediction of bank erosion rates based on BEHI ratings developed from data collected in the field.

Methods
Field data collection

Field data for BEHI parameters were collected in the fall of 2004 following the quality assurance project plan (Confluence 2004). Parameters such as length of eroding bank, height of eroding bank, bankfull height, root depth, root density, bank angle, and surface protection (**Figure H-1**) were collected for each eroding bank within each assessment reach according to methods outlined by Rosgen (2004). Locations of sample reaches are shown in **Figure H-2**.

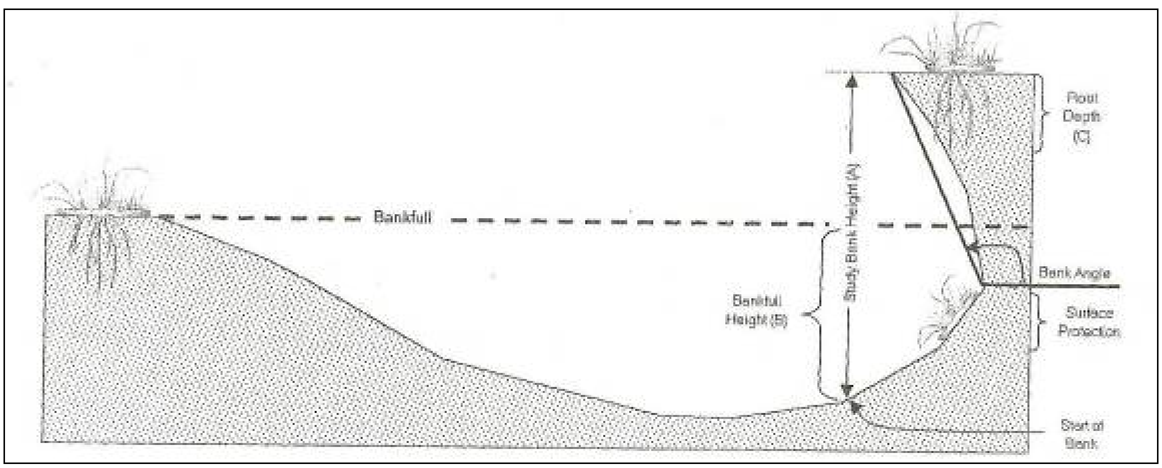

Figure H-1. BEHI Field Data Collection Methods
(Rosgen 2004)

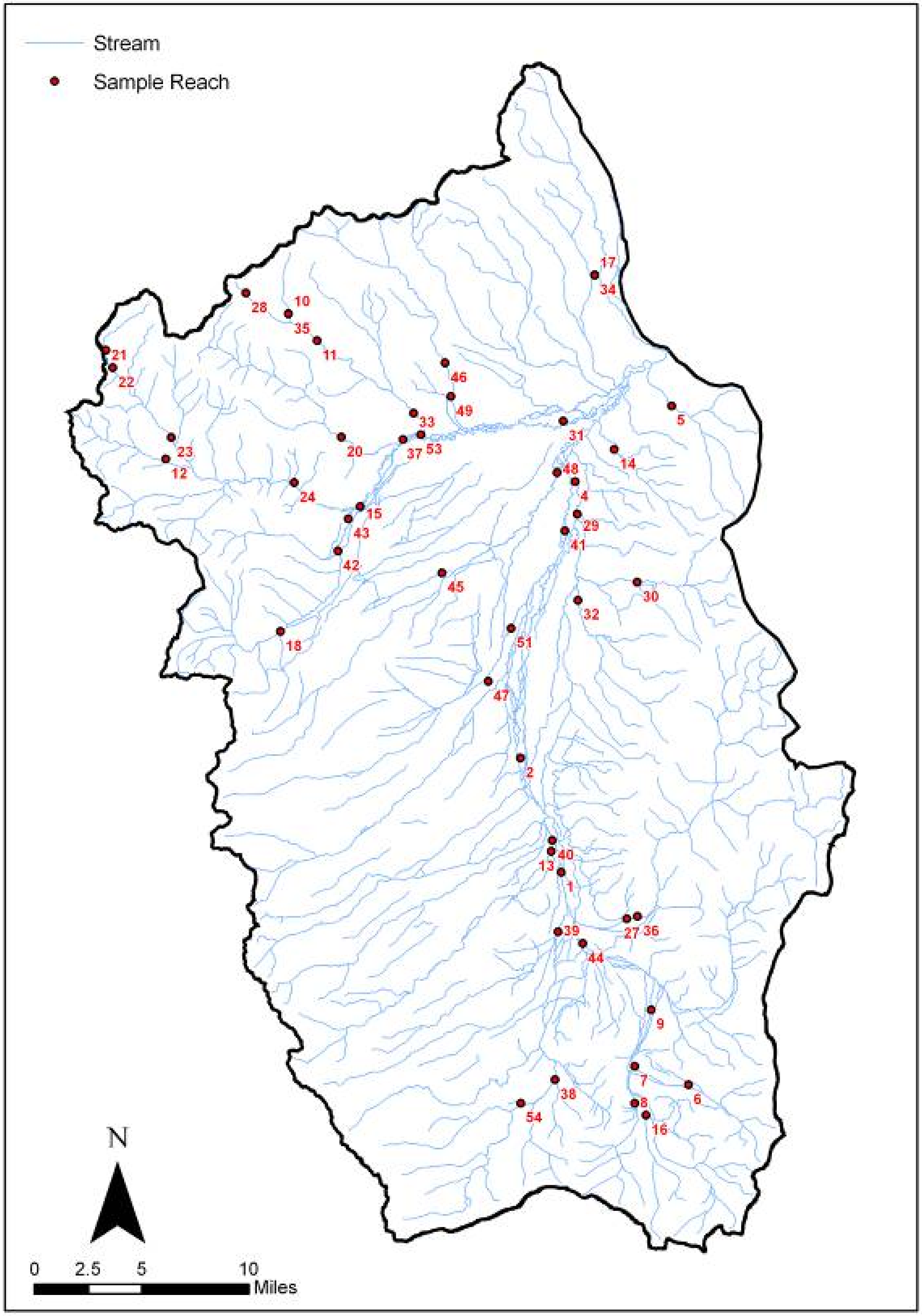

Figure H-2. Bank Erosion Assessment Sample Reach Locations

Calculation of sediment contribution from field data

Data collected in the field were used to predict the BEHI. The following data were collected for each bank.

- Bank Height, A (ft)
- Bankfull Height, B (ft)
- Root Depth, C (ft)
- Root Density, D (%)
- Bank Angle (deg.)
- Surface Protection (%)

The following erodibility variables (values) were computed and considered in ranking each bank as per Rosgen (2004).

- Bank Height / Bankfull Height, (A/B)
- Root Depth / Bank Height, (C/A)
- Weighted Root Density, (D*C/A)
- Bank Angle (deg.)
- Surface Protection (%)

The erodibility variable values were converted to numerical indices for bank erosion potential based on the relationships determined by Rosgen (2004) (**Table H-1**).

Table H-1 Conversion from Erodibility Variable Index to Numerical Bank Erosion Potential Values

(Rosgen 2004)

Erodibility Variable		Bank Erosion Potential					
		Very Low	*Low*	*Moderate*	*High*	*Very High*	*Extreme*
Bank Height / Bankfull Height	Value	1.0 - 1.1	1.11 - 1.19	1.2 - 1.5	1.6 - 2.0	21. - 2.8	> 2.8
	Index	1.0 - 1.9	2.0 - 3.9	4.0 - 5.9	6.0 - 7.9	8.0 - 9.0	10
Root Depth / Bank Height	Value	1.0 - 0.9	0.89 - 0.5	0.49 - 0.3	0.29 - 0.15	0.14 - 0.05	< 0.05
	Index	1.0 - 1.9	2.0 - 3.9	4.0 - 5.9	6.0 - 7.9	8.0 - 9.0	10
Weighted Root Density	Value	100 - 80	79 - 55	54 - 30	29 - 15	14 - 5.0	< 5.0
	Index	1.0 - 1.9	2.0 - 3.9	4.0 - 5.9	6.0 - 7.9	8.0 - 9.0	10
Bank Angle	Value	0 - 20	21 - 60	61 - 80	81 - 90	91 - 119	> 119
	Index	1.0 - 1.9	2.0 - 3.9	4.0 - 5.9	6.0 - 7.9	8.0 - 9.0	10
Surface Protection	Value	100 - 80	79 - 55	54 - 30	29 - 15	14 - 10	< 10
	Index	1.0 - 1.9	2.0 - 3.9	4.0 - 5.9	6.0 - 7.9	8.0 - 9.0	10

The BEHI method also allows the practitioner to modify the score based on bank material and bank material stratification. Rationale for exclusion of these factors from data collection and analysis related to the use of an average retreat rate assigned to each BEHI ranking. Addition of the bank material and bank material stratification to this analysis would have greatly complicated analyses without a commensurate increase in certainty in the results. Moreover, these qualitative assessments likely have low replicability. Therefore, the expense of collecting the additional data, combined with the lack of reliability in the results, justified the omission of these parameters.

A total score for each bank was developed by summing the bank erosion potential indices determined in the previous step. Finally, a BEHI ranking was assigned to the bank based on the following classification developed by Rosgen (2004).

Total Score	5 - 9.9	10 - 19.9	20 - 29.9	30 - 39.9	40 - 45	45.1 - 50
BEHI Rating	*Very Low*	*Low*	*Moderate*	*High*	*Very High*	*Extreme*

This classification was modified slightly to allow for analysis based on the Rosgen Colorado data set (**Figure H-3**). Shown here, the modification included elimination of the *Very Low* category (which was not recorded in either the Colorado data set or in the upper Big Hole sampling), and combining the *High* and *Very High* categories into one.

Total Score	10 - 19.9	20 - 29.9	30 - 45	45.1 - 50
BEHI Rating	*Low*	*Moderate*	*High - Very High*	*Extreme*

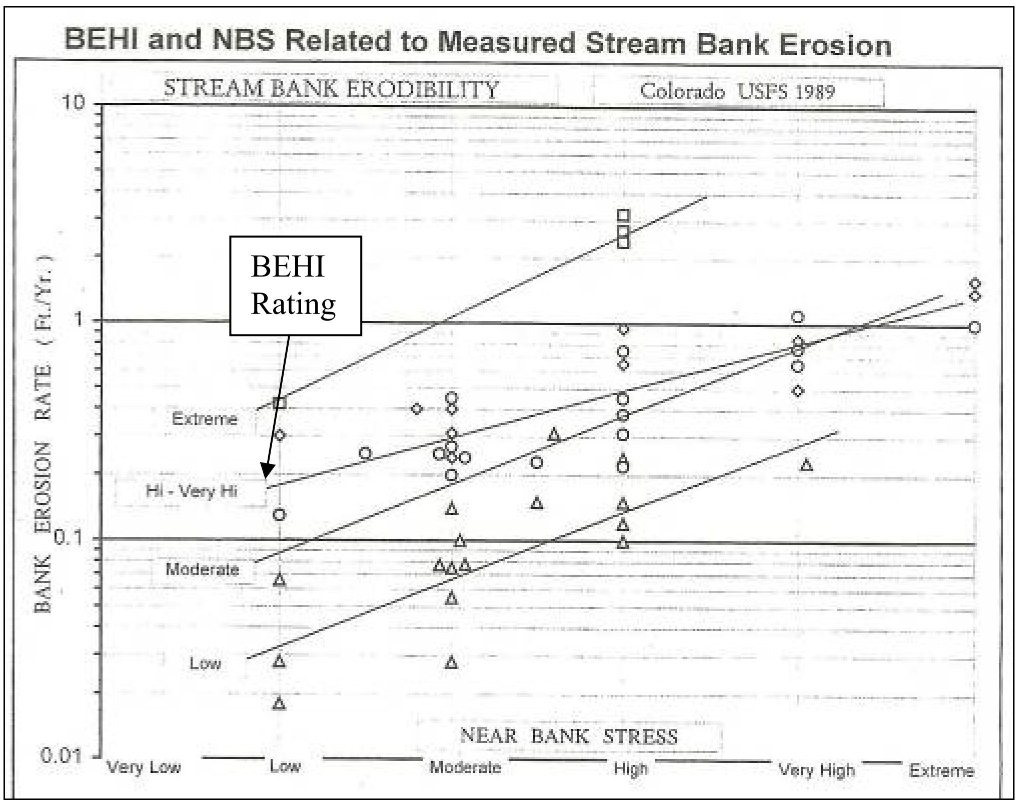

Figure H-3. Rosgen BEHI-NBS Model Developed from Colorado data (Rosgen 2001). Triangle (Δ) represents Low BEHI rating. Circle (○) represents Moderate BEHI rating. Diamond (◊) represents High/Very High BEHI rating. Square (□) represents Extreme BEHI rating.

Lateral bank erosion rate was predicted based on the modified BEHI Rating. Rosgen (2001) concluded that "there are significant differences in two or more of the means (p=0.0001) in both cases for both parameters [BEHI and NBS], thus both BEHI and NBS are highly significant predictors of bank erosion rate." This implies that BEHI rating alone can be used to estimate bank erosion rates. To apply this principle, Rosgen's Colorado dataset was reconstructed based on **Figure H-3** and reanalyzed. Mean erosion rate values were determined for each of the four BEHI rating categories described by Rosgen – Low, Moderate, High/Very High, and Extreme. The results are presented in **Table H-2**and graphically in **Figure H-4**.

Table H-2. Mean Bank Erosion Rate Based only on BEHI Rating

BEHI Rating	Mean Bank Erosion Rate (ft/yr)
Low (10-19.9)	0.096
Moderate (20-29.9)	0.438
High-Very High (30-45)	0.619
Extreme (45.1-50)	2.003

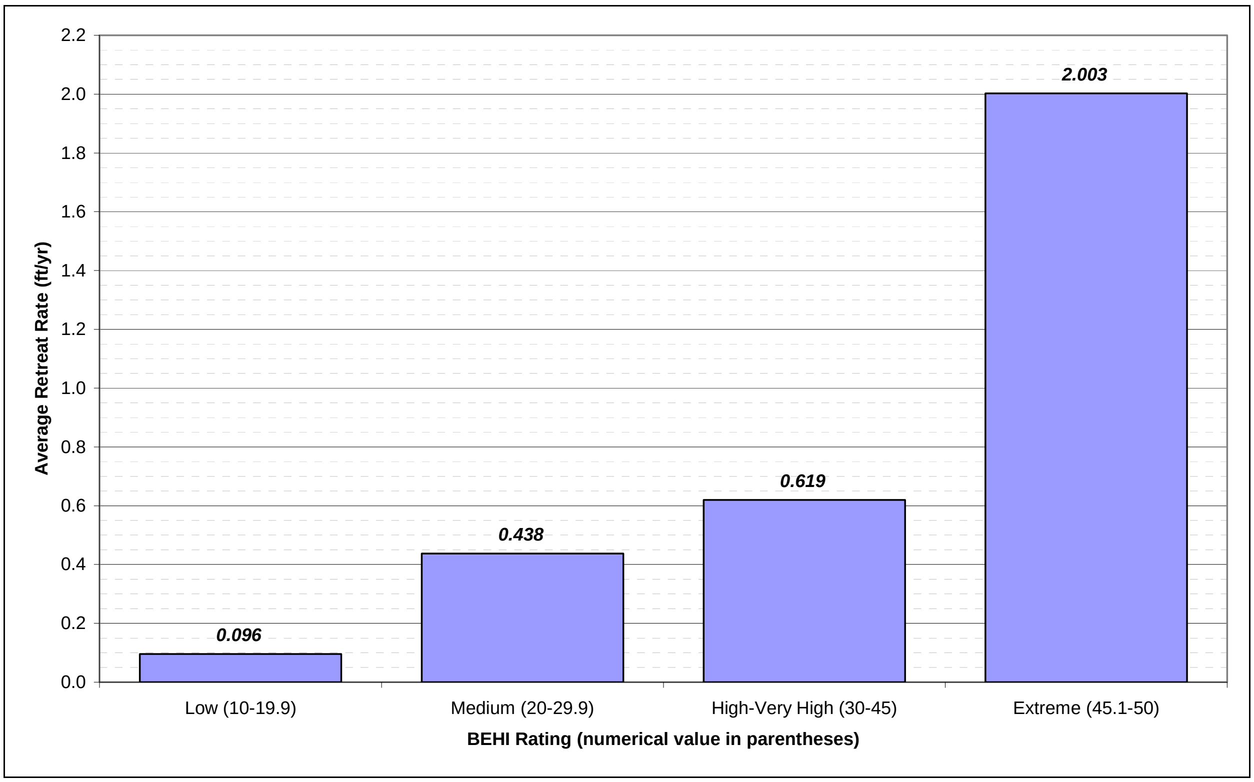

Figure H-4. Mean bank erosion rates based on BEHI rating only.

Sediment contribution from measured bank erosion sites was estimated by assigning the mean bank erosion rate to each bank based on BEHI rating, and applying Equation 1.

$$S = c \times R \times A \qquad (1)$$

Where: S = sediment load (ton/year)
c = bulk density of soil (0.084 ton/cubic foot)
R = bank erosion rate (feet/year)
A = eroding bank area (square feet)
And: A = eroding bank length (feet) x eroding bank height (feet)

The volume of all observed eroding banks was summed for each sampling reach, and divided by the length of the sampled stream reach, to arrive at an annual sediment contribution from that reach in tons/ft/yr.

Extrapolation

The average annual sediment contribution of the sampled stream reaches was used, in combination with data from an aerial photo based assessment of the streams of the upper Big Hole Watershed, to create a matrix of extrapolation factors. These extrapolation factors were then multiplied by the total length of streams within each extrapolation classification, and the results broken out by 6th Code HUC boundary (modified to reflect 303d listed stream drainages) to arrive at a predicted annual sediment contribution for each watershed.

To derive and apply the extrapolation factors, an aerial photo based assessment was performed on stream channel data for the entire upper Big Hole watershed using the National Hydrologic Dataset (NHD), overlain on USGS Digital Orthophoto Quarter Quad (DOQQ) aerial photos. Stream segments were broken out to be homogenous for, and categorized by, the following attributes:

- current Rosgen stream channel type (valley slope, valley confinement, stream slope, stream sinuosity, indications of entrenchment),
- potential Rosgen stream channel type,
- current near bank vegetation density,
- potential near bank vegetation density,
- current near bank vegetation type,
- potential near bank vegetation type, and
- current landuse.

Rosgen level 1 channel types were assigned to reaches based on the following criteria:

- B channels – low sinuosity, relatively confined, narrow floodplain, high valley and stream gradients, no extensive bar formation, relatively narrow channel widths.

- C channels – moderate sinuosity, low to moderate valley and stream gradients, gravel deposition common on point bars.

- E channels – high sinuosity, wide, low valley and stream gradients, unconfined floodplain, few observable gravel point bars.

- F channels – areas obviously altered by mechanical channelization. Although it is impossible to determine entrenchment ratio by aerial photos, channelized reaches are typically incised due to vertical erosion resulting from channelization and artificial berms along the channel margin placed during the channelization process.

- G channels – areas obviously altered by mechanical channelization and are much wider than adjacent reaches. These channels have begun the evolution from an F channel to a stable channel type and are widening to establish an inset floodplain.

The Rosgen classification assigned to each reach was ultimately not used in extrapolating sediment loads between sampled and non-sampled reaches.

The potential condition for Rosgen channel type, near bank vegetation density and near bank vegetation type were intended to reflect the state that could be achieved under best management practices. Possible values for the vegetation density assessments (both current and potential) were ‘sparse,’ ‘moderate,’ and ‘dense.’ Possible values for the vegetation type assessments (both current and potential) were ‘coniferous trees,’ ‘deciduous trees,’ ‘willow shrubs,’ and ‘herbaceous vegetation.’ Possible values for the land use assessment were ‘crop,’ ‘forested,’ ‘grazing,’ ‘hay,’ ‘logging,’ and ‘residential.’

This same aerial assessment was performed on the stream reaches that had been field sampled for bank erosion. Deriving extrapolation factors from these sample data involved looking for relationships between combinations of aerial assessment attributes and the measured erosion rate for those combinations on the sample reaches. For example, one might examine the combination of current vegetation density and land use. Given three possible values for current vegetation density (sparse, moderate, dense), and five possible values for land use (crop, forested, grazing, hay, logging, and residential), there are fifteen possible combinations of these two attributes. One may then divide the sample reach data into those fifteen categories, calculate measured bank erosion for each category, and evaluate the results to determine if the relationship between the categories and their measured erosion rates is appropriate for use in extrapolating the sample results to the watershed as a whole.

Previous work on the Upper Big Hole Valley river watershed in Southwest Montana showed that the best relationship between the aerial assessment parameters and measured erosion rates involved the combination of current vegetation density, current vegetation type, and potential vegetation type. We believe this reflects the known effect of vegetation density and type on stream bank stability (dense willow stands hold banks more strongly than sparse herbaceous vegetation, for example) as well as the effect that riparian land cover modification has on stream bank stability (streams that developed their morphology in an area of sparse herbaceous vegetation are likely to be more stable than those that developed in an area of dense woody vegetation that has since been removed).

Given that there are three possible values for current vegetation density (sparse, moderate, dense) and four possible values for both current and potential vegetation type (coniferous, deciduous, willow, herbaceous), there are 48 possible combinations of those three attributes. Some of those combinations do not 'make sense' and do not actually occur, however. For example, a stream segment should not have a current vegetation type of 'willow' and a potential vegetation type of 'herbaceous' as that does not reflect the expected result of best management practices. This reduces the number of possible combinations to 30, still too many for a meaningful extrapolation based upon 52 sample reaches – most of the possible combinations would have too few (or no) corresponding samples. A further reduction in possible combinations can be achieved by considering that, with respect to current and potential vegetation type, what is important from the standpoint of streambank erosion is whether or not the site is achieving its potential vegetation type. For example, sites that currently have herbaceous vegetation might have the potential to have herbaceous, willow, deciduous, or coniferous vegetation – four potential categories. These four categories can be reduced to two by considering a herbaceous site to be 'achieving its potential' if its potential is to support herbaceous vegetation and 'not achieving' if it has the potential to support any of the other three higher seral stages.

Reclassifying the vegetation type combinations according to 'achieving' or 'underachieving' results in 24 combinations. The number of samples corresponding to each of these 24 combinations is shown in **Figure H-5**.

Vegtype & Vegtype Potential & VegDensity

Sparse Veg

	Herbaceous	Willow	Deciduous	Coniferous
Achieving		6		
Underachieving	6			

Moderate Veg

	Herbaceous	Willow	Deciduous	Coniferous
Achieving	3	15		1
Underachieving				

Dense Veg

	Herbaceous	Willow	Deciduous	Coniferous
Achieving		17		2
Underachieving				2

Figure H-5. Extrapolation Matrix Showing the Distribution of Vegetation Type, Density, and Potential for Sample Sites

Of the 24 possible combinations, only eight are represented in the sample data. However, not all of the combinations are found in the watershed, and thus in need of an extrapolation factor. In **Figure H-5**, green cells represent combinations for which samples exist. Grey cells represent combinations which do not appear in the data for the watershed as a whole. Red cells represent combinations which do appear in the data for the watershed as a whole, but for which there are no samples. Thus, the sample data cover seven of the twelve combinations found in the watershed as a whole.

To judge whether or not this coverage is sufficient to develop a meaningful extrapolation, we looked at the proportion of the watershed as a whole that were covered by the sampled combinations.

	Vegtype & Vegtype Potential & VegDensity			
		Sparse Veg		
	Herbaceous	Willow	Deciduous	Coniferous
Achieving	648,755	432,942	0	5,293
Underachieving	740,135	0	0	0
		Moderate Veg		
	Herbaceous	Willow	Deciduous	Coniferous
Achieving	495,475	1,252,851	0	356,656
Underachieving	60,793	0	0	0
		Dense Veg		
	Herbaceous	Willow	Deciduous	Coniferous
Achieving	142,133	853,325	1,881	2,322,971
Underachieving	0	0	0	0

Figure H-6. Extrapolation Matrix Showing the Length of Stream Channel for each Vegetation Type, Density, and Potential for the Upper Big Hole Watershed

As shown in **Figure H-6**, approximately 88% of the stream segments (by length) in the valley were represented by the sampled categories, and 90% of the remainder were in a single category (sparse, herbaceous, achieving), for which an appropriate factor could be easily derived from the sample data. A meaningful extrapolation to the watershed as a whole can be performed using these data.

The average erosion rate (tons/ft/yr) was calculated for all of the combinations that had been sampled, resulting in **Figure H-7**.

Vegtype & Vegtype Potential & VegDensity

Sparse Veg	Herbaceous	Willow	Deciduous	Coniferous
Achieving		0.033814066		*
Underachieving	0.034815185			

Moderate Veg	Herbaceous	Willow	Deciduous	Coniferous
Achieving	0.016274753	0.013261281		0
Underachieving	*			

Dense Veg	Herbaceous	Willow	Deciduous	Coniferous
Achieving		0.015713095	*	0.001784176
Underachieving				

Figure H-7. Extrapolation Matrix – The Average Erosion Rate Tons/ft/yr) for each Site Type Sampled Asterisks denote categories with minimal representation in the watershed.

From this starting point, a final extrapolation factor matrix was derived using best professional judgment, as follows:

- Herbaceous:

In all cases, reaches exhibiting an "achieving" potential were assigned a lower loading rate than those exhibiting an "underachieving" potential Likewise, reaches exhibiting dense vegetation were assigned a lower erosion rate than moderate and sparse densities. All herbaceous categories were assigned higher sediment loads than the corresponding density and potential for willow stands (i.e. a moderate density, herbaceous reach achieving its vegetation potential was assigned a higher sediment load than a moderate density, willow dominated reach achieving its vegetation potential) because herbaceous stands typically exhibit higher erosion rates than willow stands.

- Willow

All three willow vegetation density categories were field measured and assigned an "achieving" potential. However, the sediment load measured for the dense category of willows indicated a higher sediment load than the moderate density category. Best professional judgment was used to infer that a dense stand of willows should exhibit a lower sediment load than a moderate stand. Therefore, the dense, achieving reaches were reassigned a sediment load rate slightly lower than the moderate, achieving reaches. These dense, achieving reaches were assigned a sediment load of 0.010 tons/ft/year (measured load was 0.016 tons/ft/year). Moderate and sparse reaches with achieving potential loads were not altered from their measured loading rates.

- Deciduous

Only one category of deciduous dominated vegetation reaches existed; a dense stand exhibiting its potential density. This reach type was not field measured, therefore a sediment load value was assigned based on other sediment load values. Best professional judgment was used to infer that a dense stand of deciduous vegetation likely exhibits a moderate, herbaceous understory. Therefore, the assigned sediment load rate (0.018 tons/ft/yr) was chosen to closely match the moderate density, achieving potential, herbaceous reaches (0.0163 tons/ft/yr). Although deciduous roots provide some bank stability due to their massive root systems, they are typically not as effective as the fibrous network of shrub and herbaceous roots. Therefore a slightly higher loading rate was assigned to the dense, deciduous-dominated stand versus the moderate, herbaceous stand.

- Coniferous

Reaches exhibiting a coniferous-dominated vegetation type almost exclusively fall within a hillslope classification of greater than 4% in the Upper and North Fork Big Hole Watershed. Streams flowing across slopes >4% are A and B channels, which typically exhibit cobble and boulder bed morphology in this study area. These bed forms generally provide excellent bank stability in the form of narrow, step pools and steep riffles. Erosion rates in these streams are typically very low due to the bed material preventing vertical and lateral scouring. Not surprisingly, stream bank sediment loads measured within dense, coniferous reaches achieving their vegetation potential were lower than all other reach types (0.0018 tons/ft/yr).

As coniferous stand density is reduced from dense to sparse, sediment loads should not significantly change, because in steeper drainages in this watershed area bed features control erosion rather than vegetation types and density. Therefore, sediment loads in reaches exhibiting moderate and sparsely vegetated conifer stands were assigned slightly higher loads than the densely vegetated stands.

The resulting extrapolation factor matrix is given in **Figure H-8**.

Vegtype & Vegtype Potential & VegDensity

	Herbaceous	Willow	Deciduous	Coniferous
Sparse Veg				
Achieving	0.02	0.0338		0.01
Underachieving	0.0348			
Moderate Veg				
Achieving	0.0163	0.0133		0.005
Underachieving	0.03			
Dense Veg				
Achieving	0.012	0.01	0.018	0.0018
Underachieving				

Figure H-8. Extrapolation Matrix of the Average Loading Rate (tons/ft/yr) for each Site Type

These factors were applied to all of the stream channel segments for the Big Hole watershed, total sediment load from existing conditions calculated, and the results summarized by sub-watershed.

To estimate the sediment produced under best management practices, each stream segment in the watershed was assigned an extrapolation factor based upon that segment's potential vegetation type and density, total sediment load from BMP conditions calculated, and the results summarized by sub-watershed.

Example: A stream segment was classified by the aerial assessment as currently having moderate, herbaceous vegetation cover. This stream segment was also classified as having the potential to support dense willow cover. This stream segment would be assigned the extrapolation factor for moderate, herbaceous, underachieving (0.03 tons/ft/yr) to reflect its sediment delivery under existing conditions, and the factor for dense, willow, achieving (0.01) to reflect its potential sediment delivery under BMP.

Results

Table H-3 presents the existing and potential bank erosion loads by 6th code HUC sub-watershed. **Table H-4** presents the results reported by surface land ownership classification.

Table H-3. Bank erosion loads by 6th code HUC sub-watershed.

6th Code Huc WS (Mod for 303d)	Length of Streams in WS (ft)	Estimated Current Sediment Delivery (ton/yr)	Estimated Potential Sediment Delivery (ton/yr)
Andrus Creek	158,037	3,106	1,411
Berry Creek	63,938	115	115
Big Swamp Creek	160,963	1,175	644
Big Hole River-Big Swamp Creek	219,221	4,645	2,034
Big Hole River-McVey Homestead	206,932	3,647	3,101
Big Hole River-Saginaw Creek	164,496	2,972	1,461
Big Hole River-Spring Creek	221,595	3,563	2,592
Big Hole River-Squaw Creek	88,626	1,252	902
Big Hole River-Wisdom	278,607	6,012	3,166
Big Lake Creek	279,616	5,167	2,373
Bull Creek	248,229	4,534	2,569
Doolittle Creek	104,967	596	360
Englejard Creek	166,425	1,392	953
Fox Creek	95,167	1,671	745
Francis Creek	139,896	1,625	1,203
Headwaters Big Hole River	150,887	909	741
Howell Creek	137,297	1,864	850
Johnson Creek	166,451	1,135	810
Joseph Creek	89,420	662	469
Little Lake Creek	155,528	1,525	1,013
Lower Governor Creek	237,202	5,645	2,735
Lower Rock Creek	91,825	2,500	1,766
Lower Trail Creek	178,277	772	759
Lower Warm Springs Creek	273,215	4,306	2,852
May Creek	110,953	409	409
McVey Creek	101,633	1,339	866
Miner Creek	173,301	1,326	1,152
Mussigbrod Creek	153,143	1,058	857
North Fork Bighole River	348,852	5,039	3,843
Old Tim Creek	109,531	1,581	1,198
Pine Creek	40,745	604	227
Pintler Creek	160,145	1,222	1,140
Plimpton Creek	277,692	3,225	2,307
Ruby Creek	238,309	1,715	1,598
Schulz creek	17,672	32	32
Stanley Creek	131,206	2,844	1,674
Steel Creek	164,910	1,755	910
Swamp Creek	281,630	4,123	2,889
Tie Creek	194,539	876	656
Upper Governor Creek	133,856	2,251	1,112
Upper Rock Creek	164,268	2,409	1,366
Upper Trail Creek	174,824	1,283	970
Upper Warm Springs Creek	121,202	1,460	1,133
West Fork Ruby Creek	137,982	878	832
Total for Upper Big Hole Watershed	7,313,208	96,218	60,796

Table H-4. Bank erosion rates by land ownership.

Ownership Classification	Length of Streams on ownership (ft)	Estimated Current Sediment Delivery (ton/yr)	Estimated Potential Sediment Delivery (ton/yr)
OTHER	3,315,581	67,915	39,037
State Government	315,199	6,236	4,201
US Government	1,502	20	18
USDA Forest Service	3,669,892	21,901	17,430
USDI National Park Service	11,034	147	110
Grand Total	7,313,208	96,218	60,796

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APPENDIX I
BIG HOLE RIVER WATERSHED NUTRIENT TMDL
GWLF MODELING DOCUMENTATION

K. Flynn and D. Kron
TMDL Technical Report DMS-2008-10

DOCUMENT PURPOSE

This document has been prepared to support nutrient source assessments and loading estimates for the Big Hole River Watershed Nutrient TMDL. It is intended to provide a brief synopsis of the project and substantiate numerical estimates of nitrogen and phosphorus delivery in the watershed. Work has been completed cooperatively by the Water Quality Modeling and Planning Sections of the Montana Department of Environmental Quality.

LIST OF ACRONYMS

ACRONYM

AMC	Antecedent Moisture Condition
AU	Animal Units
AUM	Animal Units per Month
ARM	Administrative Rules of Montana
AWC	Available Water Capacity
BMPs	Best Management Practices
CN	Curve Number
CMPPCT	Composition Percentage
CN	Curve Number
COOP	Cooperative Observer
CWA	Clean Water Act
CWAIC	Clean Water Act Information Center
DEQ	Montana Department of Environmental Quality
EMC	Event Mean Concentration
EPA	Environmental Protection Agency
GIS	Geographic Information System
GRTS	Grants Reporting and Tracking System
GWLF	Generalized Watershed Loading Functions
HUC	Hydrologic Unit Code
K	Soil Erodibility Factor
LULC	Land Use/Land Cover
MOS	Margin of Safety
MUID	Map Unit ID
N	Nitrogen
NRCS	Natural Resource Conservation Service
NED	National Elevation Datum
NHD	National Hydrography Dataset
NLCD	National Land Cover Dataset
NO2+NO3	Nitrate plus Nitrite
NPS	Nonpoint Source
NURP	Nationwide Urban Runoff Program
NWIS	National Water Information System
P	Phosphorus
SCS	Soil Conservation Service
SDR	Sediment Delivery Ratio
SNOTEL	Snow Telemetry System
SRP	Soluble Reactive Phosphorus
SSC	Suspended Sediment Concentration
STATSGO	State Soil Geographic Database
STORET	Storage and Retrieval Water Quality Database
TN	Total Nitrogen
TP	Total Phosphorus

TMDL	Total Maximum Daily Load
TPA	TMDL Planning Area
USGS	U.S. Geological Survey
USLE	Universal Soil Loss Equation

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SECTION 1.0 INTRODUCTION

Nineteen tributaries are characterized as "water quality-limited" in the Big Hole River watershed due to nutrient impairment (Table ; CWAIC, 2008). To satisfy Federal Clean Water Act requirements, Total Maximum Daily Loads (TMDLs) must be developed for these water bodies such that they support beneficial uses. As part of this effort, a low-detail modeling study was completed by Montana Department of Environmental Quality (DEQ) to estimate nutrient source contributions and seasonal loadings of nitrogen and phosphorus from various land uses. The Generalized Watershed Loading Functions (GWLF) model was selected for the analysis due to its relative simplicity in model application and usefulness in simulating hydrology and mass loadings of pollutants on a monthly time-scale. Due to current TMDL scheduling priorities, only a subset of the impaired water bodies in each TMDL Planning Area (TPA) were evaluated as part of the current TMDL effort. The remaining tributaries will be addressed according to the scheduling timeframes outlined in the consent decree. A map of the 303(d) listed reaches evaluated as part of this project are shown in **Figure 1.**

Table 1. Water quality limited reaches in the Big Hole River watershed impaired from nutrients.

Water body ID[1,2]	Reach Segment	Probable Cause
Upper TPA[3]		
Francis Creek	MT41D004_200	Nitrogen/Phosphorus (total)
Steel Creek	MT41D004_190	Phosphorus (total)
McVey Creek	MT41D004_210	Nitrogen/Phosphorus (total)
Rock Creek	MT41D004_120	Nitrogen/Phosphorus (total)
Swamp Creek	MT41D004_110	Nitrogen/Phosphorus (total)
Fox Creek	MT41D004_170	Phosphorus (total)
Pine Creek	MT41D004_160	Phosphorus (total)
Warm Springs Creek	MT41D004_180	TKN/Phosphorus (total)
Middle TPA[3]		
Jerry Creek	MT41D003_020	Excess algal growth
Charcoal Creek	MT41D002_150	Nitrogen/Phosphorus (total)
Fishtrap Creek	MT41D003_160	Phosphorus (Total)
Gold Creek	MT41D003_230	Phosphorus (Total)
Sawlog Creek	MT41D004_230	Phosphorus (Total)
Lower TPA[3]		
Camp Creek	MT41D002_020	Phosphorus (Total)
Divide Creek	MT41D002_040	TKN/Phosphorus (Total)
Grose Creek	MT41D002_060	Phosphorus (Total)
Lost Creek	MT41D002_180	Nitrogen/Phosphorus (total)
Soap Creek	MT41D002_140	Phosphorus (Total)
Wickiup Creek	MT41D002_120	Phosphorus (Total)

[1] Source: 2006 303(d) List.
[2] Items shown in white are being addressed as part of the current TMDL effort. Greyed items will be addressed at a later date.
[3] TPA (TMDL Planning Area) segments are subsets of the overall Big Hole River Watershed used to divide the project area into manageable units for TMDL planning.

1.1 Previous Studies

A literature review was completed prior to the initiation of the project to identify if previous studies would be of use in modeling. Those of interest to DEQ are shown below:

1. **USGS bi-weekly monitoring** – USGS collected bi-weekly nitrate (NO3-) and daily sediment samples in the lower portion of the Big Hole River watershed from 1960-1964. Sediment is of interest due to its affinity for nutrient sorption.
2. **Statewide water quality monitoring network monitoring** – DEQ conducted nutrient sampling at multiple locations in the watershed from 2003-2005 as part of the statewide monitoring network. Sampling was limited to a frequency of once per year, in the growing season.
3. **TMDL source assessment monitoring** – DEQ monitored nutrients at multiple sites from 2003 and 2005 as part of TMDL source assessment activities. Data collection was limited to the growing season, with a frequency of one to two samples per summer.

The pertinence of these studies toward the modeling is detailed further in subsequent sections. Applicability toward nutrient criteria is described below.

1.2 Nutrient Criteria in Montana (ARM 17.30.637)

Montana is currently governed by narrative nutrient criteria, specifically, that surface waters must be free from municipal, industrial, and agricultural discharges that produce undesirable aquatic life [ARM 17.30.637 (1)(e)]. In instances where water bodies do not support beneficial uses, TMDLs and associated water quality restoration plans must be developed. Nineteen such tributaries were identified as impaired on the 2006 303(d) List. Nine are being addressed as part of the Big Hole River watershed TMDL (**Table 1**). Because narrative criteria are somewhat problematic for total maximum daily load analysis, interim numeric criteria were used as a surrogate instead. Those applicable for the Big Hole River TMDL (e.g. the Middle Rockies Ecoregion) are shown in **Table 2**. Modeling will be conducted to assess strategies that can be implemented such that these interim criteria are achieved.

Table 2. Interim numeric criteria for the Big Hole River Watershed (Suplee et al., 2007).

Constituent	Target Value
Total nitrogen (TN)	≤ 0.39 mg/L (winter) ≤ 0.52 mg/L (runoff) ≤ 0.32 mg/L (growing season)
Total phosphorus (TP)	≤ 0.03 mg/L (winter) ≤ 0.05 mg/L (runoff) ≤ 0.049 mg/L (growing season)
Chlorophyll a	≤ 150 mg/m² for Foothill/Valley

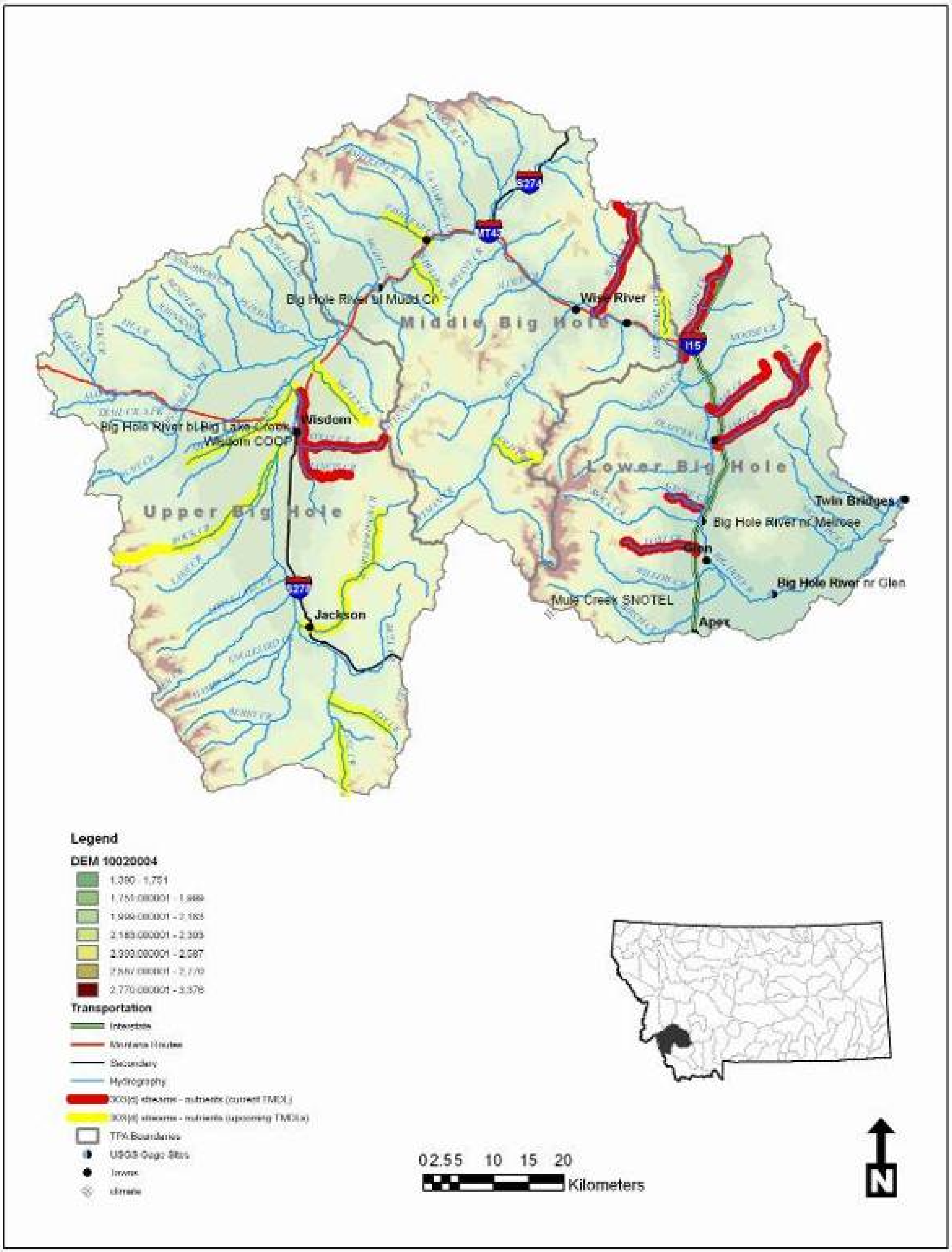


Figure 1. Study of map showing 303(d) listed stream segments, elevation and terrain (DEM), streamflow gaging stations, climate stations, and transportation network. Stream segments highlighted in red are being addressed in the current TMDL. The remaining listings will be completed at a later date.

SECTION 2.0
STUDY AREA

The Big Hole River drains approximately 7,250-km2 (2,800-mi2) of high- and mid-elevation mountainous topography in southwestern Montana. Originating from the continental divide, the river flows 247-km past the towns of Jackson, Wisdom, Wise River, Melrose, and Glen before reaching its endpoint near Twin Bridges (**Figure 1**). Elevations in the watershed range from 1,399 to 3,388 meters (4,590 to 11,115 feet), and mean basin elevation is 2,149 meters (7,050 feet). The entire watershed is part of United States Geological Survey (USGS) Hydrologic Unit Code (HUC) 10020004. Three distinct planning segments are being addressed by DEQ as part of the TMDL. These include: (1) the upper TPA which extends from the headwaters to Pintlar Creek, (2) middle TPA which extends from Pintlar Creek to Divide Creek, and (3) lower TPA which extends from Divide Creek to the Beaverhead River.

2.1 Climate

Climate in the Big Hole River watershed is inter-montane continental, with marked seasonality. Wisdom cooperative observer (COOP) station 249067 and the Mule Creek SNOTEL station provide representative information regarding the basin (**Table 3**, **Figure 2a**). Valleys are predominantly arid, and the mountains wet, with a 30-year average annual precipitation at Wisdom of 30.2 centimeters (11.9 inches) (1971-2000). The Mule Creek SNOTEL receives nearly double this amount; 76.6 centimeters annually (30.2 inches). The observed variation in precipitation is typical of climates in mountainous regions and has been described previously by Farnes (1975) and Marvin and Voller (2000). Temperatures are also consistent with mountainous climates with warmer valleys and cooler uplands, the exception being during the winter months when inversions occur. Mean monthly temperature at Wisdom is 2.0ºC (35.6ºF) while the Mule Creek SNOTEL site is 0.8ºC (33.4ºF).

Table 3. Representative climate stations for the Big Hole River Watershed (1971-2000).

Station ID	Agency	Elevation	Mean Annual Precipitation	Mean Annual Temperature[1]
Wisdom COOP 249067 (valley)	NOAA	1847 m (6060 ft)	30.2 cm (11.9 inches)	2.0ºC (35.6ºF)
Mule Creek SNOTEL (mountain)	NRCS	2530 m (8300 ft)	76.6 cm (30.2 inches)	0.8ºC (33.4ºF)

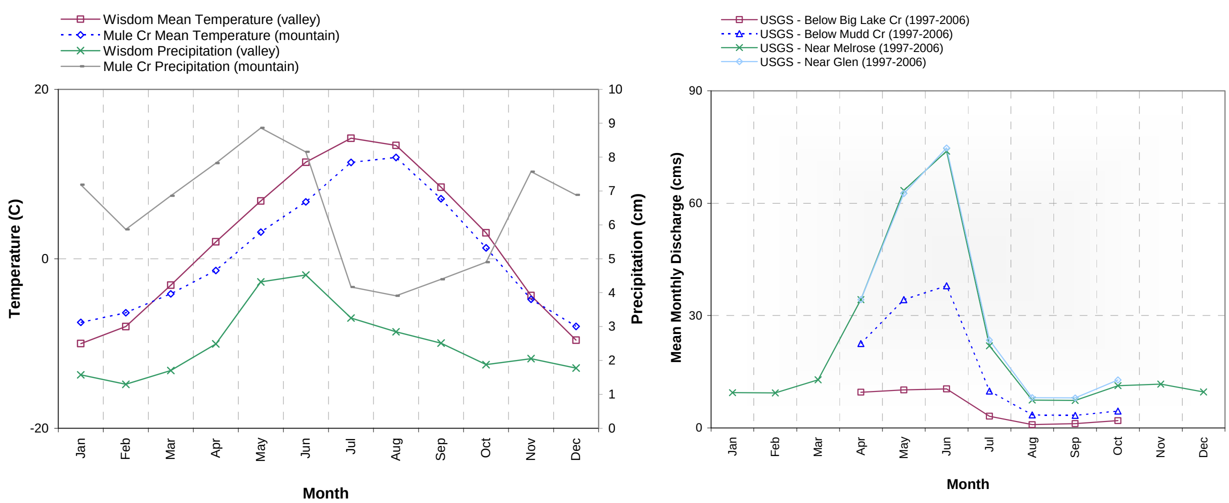
[1] Mean annual temperature statistics not compiled by NRCS for 1971-2000. Entire period of record used instead.

2.2 Streamflow

There are four operational USGS gaging stations in the Big Hole River watershed: (1) USGS 06024450 Big Hole River below Big Lake Creek at Wisdom, MT, (2) USGS 06016000 Big Hole River below Mudd Creek, (3) USGS 06017000 Big Hole River nr Melrose, and (4) USGS 06018500 Big Hole River nr Glen. Based on review of their hydrographs, surface water hydrology is predominately snowmelt driven, with spring snowmelt beginning in mid to late March, peaking in June, and then rapidly declining in July and August toward baseflow (**Figure 2b**). Baseflow and/or low flow conditions then persist to the following spring when winter snow accumulation once again begins to melt.

2.3 Land Use

Land use in the Big Hole River consists primarily of agriculture, with cow-calf operations being the dominant production practice. Many stock owners pasture their livestock on National Forest range during the summer months and grow irrigated grass or alfalfa hay for winter feed. In the headwaters, logging and associated activities, such as road construction, have been known to occur, but only to a minor extent. The same goes for urban encroachment and residential development. No point source discharges or wastewater discharges were identified in the watershed and the towns of Jackson, Wisdom, Wise River, Melrose, and Glen all have relatively low septic densities, all under 200 people (U.S. Census, 2000).



a) b)

Figure 2. a) Climate at Wisdom COOP 249067 (valley) and Mule Creek SNOTEL (mountainous) sites (1971-2000); b) hydrology at the four operational USGS gages in the watershed (1997-2006).

2.4 Soil

Soils in the Big Hole River watershed are highly variable and depend on location. In general they have moderate infiltration rates and consist mainly of deep well drained soils with fine to coarse textures. The Maurice-Phillipsburg-Thayne loam is the predominant soil series in the Upper Big Hole River TPA. It is found at the lower elevations between Jackson and Wisdom. The Ovando-Elkner-Shadow is a gravelly-silt-loam found at mid elevations of the Pintler and Pioneer Mountains, and dominates the Middle Big Hole River Planning Area. Finally, the Trimad-Kalsted-Crago is a silt-loam found throughout much of the Lower Big Hole River Planning Area

(DEQ, 2007). Soils information was acquired from the State Soil Geographic (STATSGO) database (NRCS, 1994).

SECTION 3.0
DATA COMPILATION & ASSESSMENT

A data compilation and assessment was initially completed to identify available information for modeling. Two types of data were assessed: (1) flow data and (2) water chemistry data. Both the USGS National Water Information System (NWIS, 2008) and the U.S. Environmental Protection Agency's (EPA) STORET databases (STORET, 2008) were queried. Results are briefly described below.

3.1 Flow

Observed streamflow is a required component for hydrologic calibration and was obtained directly from the USGS. Gaging stations that have historically operated in the Big Hole River watershed are shown in **Table 4**, and most contain suitable observational data for modeling (e.g. daily streamflow). Periods of record and associated water quality observations are also indicated.

Table 4. USGS streamflow and water quality stations in the Big Hole River Watershed.

USGS No.	Site Name	Begin Date	End Date	# of Nutrient Observ.	# of SSC Observ.
6025270	Moose Cr ab Maclean Cr nr Divide MT	10/1/1997	9/30/1999	0	0
6025480	Rock Cr bl Brownes Lake nr Glen MT	9/1/1997	10/31/1999	0	0
6025700	Willow Cr Diversions to Birch Cr nr Glen MT	4/21/1946	9/30/1966	0	0
6026206	Upper Raffety Ditch near Glen MT	4/24/1998	10/31/1999	0	0
6024510	West Fork Ruby Creek near Wisdom MT	4/1/1995	9/30/1996	0	0
6024000	Miner Creek near Jackson MT	5/24/1948	10/31/1953	0	0
6025800	Willow Creek near Glen MT	8/1/1962	10/31/1999	36	21
6026000	Birch Creek near Glen MT	5/1/1946	10/6/1976	21	15
6023500	Big Hole River near Jackson MT	4/29/1948	10/31/1953	0	0
6024470	Swamp Creek near Wisdom MT	3/28/1995	9/30/1996	0	0
6024500	Trail Creek near Wisdom MT	6/29/1948	7/20/1972	2	0
6024590	Wise River near Wise River MT	9/28/1972	9/30/1985	0	0

Table 4. USGS streamflow and water quality stations in the Big Hole River Watershed.

USGS No.	Site Name	Begin Date	End Date	# of Nutrient Observ.	# of SSC Observ.
6024450	Big Hole River bl Big Lake Cr at Wisdom MT	5/1/1988	5/11/2008	0	0
6024540	Big Hole River bl Mudd Cr nr Wisdom MT	10/1/1997	5/11/2008	0	0
6024580	Big Hole River near Wise River MT	6/1/1979	10/2/1981	0	0
6025000	Big Hole River near Dewey MT	9/1/1910	9/30/1913	0	0
6025250	Big Hole River at Maiden Rock nr Divide MT	10/1/1997	5/11/2008	0	0
6025500	Big Hole River near Melrose MT	10/1/1923	5/11/2008	102	1465
6026210	Big Hole River near Glen MT	9/11/1997	5/11/2008	0	0
6026400	Big Hole River near Twin Bridges MT	7/25/1979	10/1/1981	50	0
6026420	Big Hole R bl Hamilton Ditch nr Twin Bridges, MT	7/1/2007	9/30/2007	0	0

3.2 Chemistry

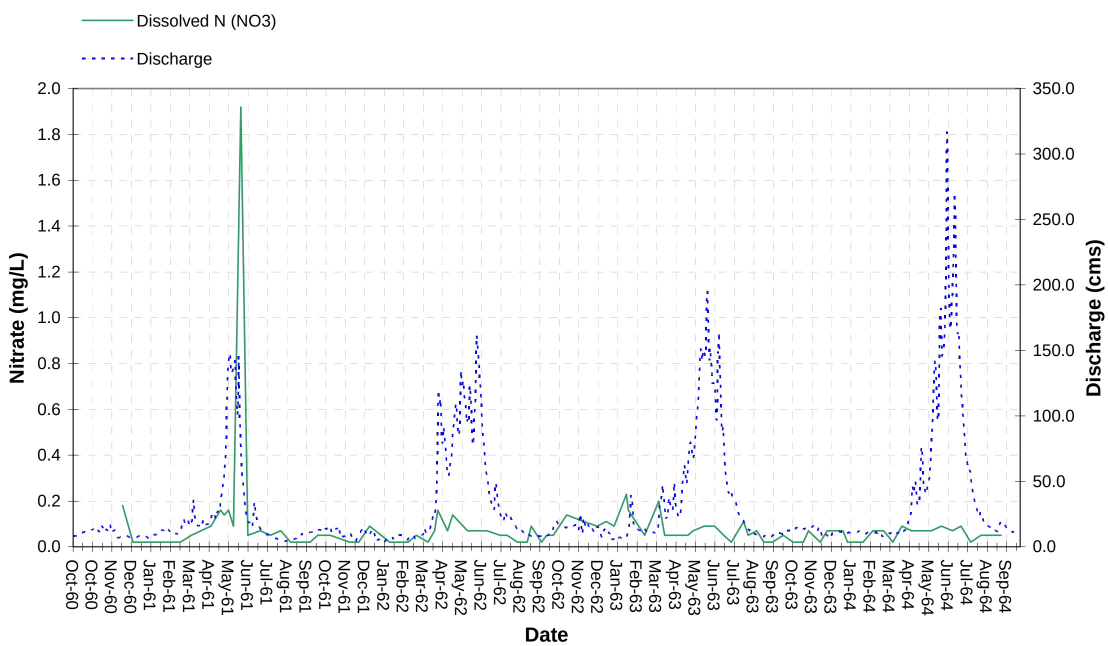
Water chemistry data are necessary for quality calibration. As such, the USGS and STORET records were evaluated to ensure suitability for modeling. Based on this reconnaissance, only a handful of sites have adequate sediment and nutrient observations for modeling. This includes USGS 6025800 Willow Creek near Glen and USGS 6025500 Big Hole River near Melrose, MT. No suitable data were found in STORET. Thus a calibration and validation approach was formulated around those stations. This is described in **Section 3.6**. An assessment of this data is provided in the following section.

3.3 Data Assessment

3.3.1 Time Series

Bi-weekly nutrient samples (NO3-) and daily suspended sediment samples were collected at USGS 06017000 Big Hole River near Melrose from 1960-1964. Monthly nutrient and SSC samples were collected at USGS 6025800 Willow Creek near Glen from 1962-1965. Based on the data, pollutant loading is consistently correlated with early season hydrograph response (**Figure 3** and **Figure 4**). Fluctuations in nitrate appear to be infrequent short duration events which presumably are associated with overland flow from agricultural landscapes. Sediment peaks are more prolonged and are believed to occur primarily from bank erosion during sustained snowmelt (rather than rainfall induced upland erosion).
3.3.2 Graphical and statistical analysis

STORET contains a wealth of standalone water chemistry data. A population based approach was used to estimate cursory statistical information from STORET, such as mean and median concentrations, upper and lower quartiles, and ranges for total nitrogen (TN), nitrate (NO_3^-), total phosphorus (TP), and soluble reactive phosphorus (SRP) (**Figure 5**). In general, nutrient concentrations appear to have remained relatively consistent over time, with dissolved nitrogen (e.g. NO_3^-) exhibiting the most variability. This largely is consistent with the hypothesis that overland flow infrequently contributes dissolved loadings during the runoff period.



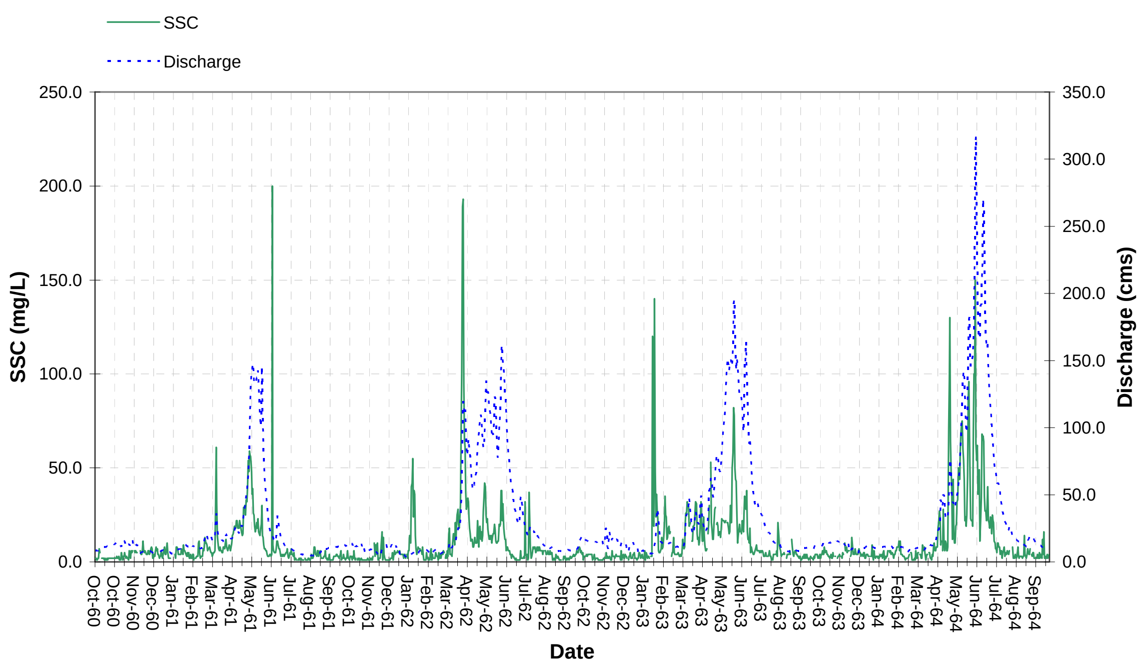
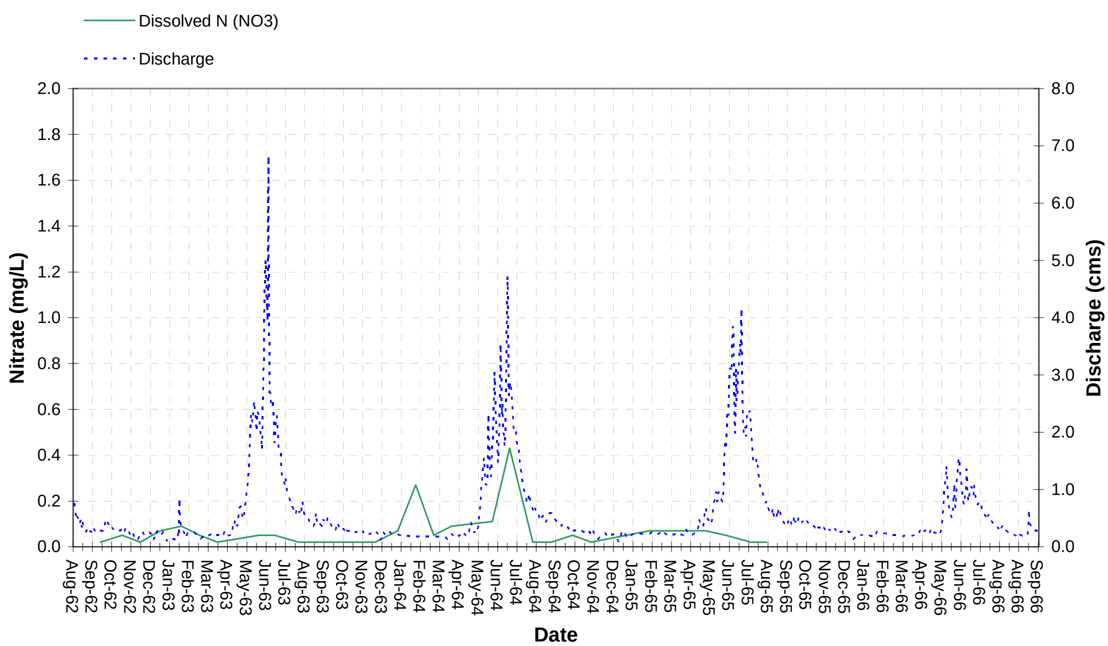


Figure 3. Biweekly nitrate concentrations (NO3--), daily suspended sediment concentration (SSC), and daily flow at USGS 06017000 Big Hole River near Melrose.



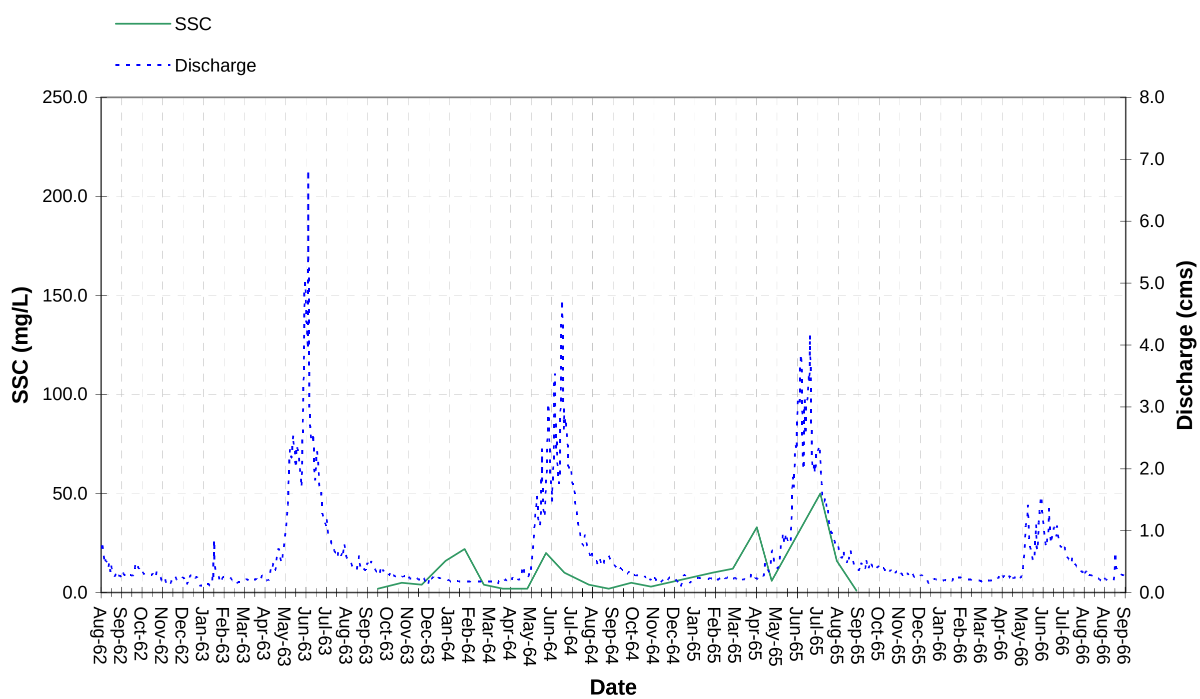


Figure 4. Monthly nitrate (NO3-) and suspended sediment (SSC) concentration, and daily flow at USGS 6025800 Willow Creek near Glen.

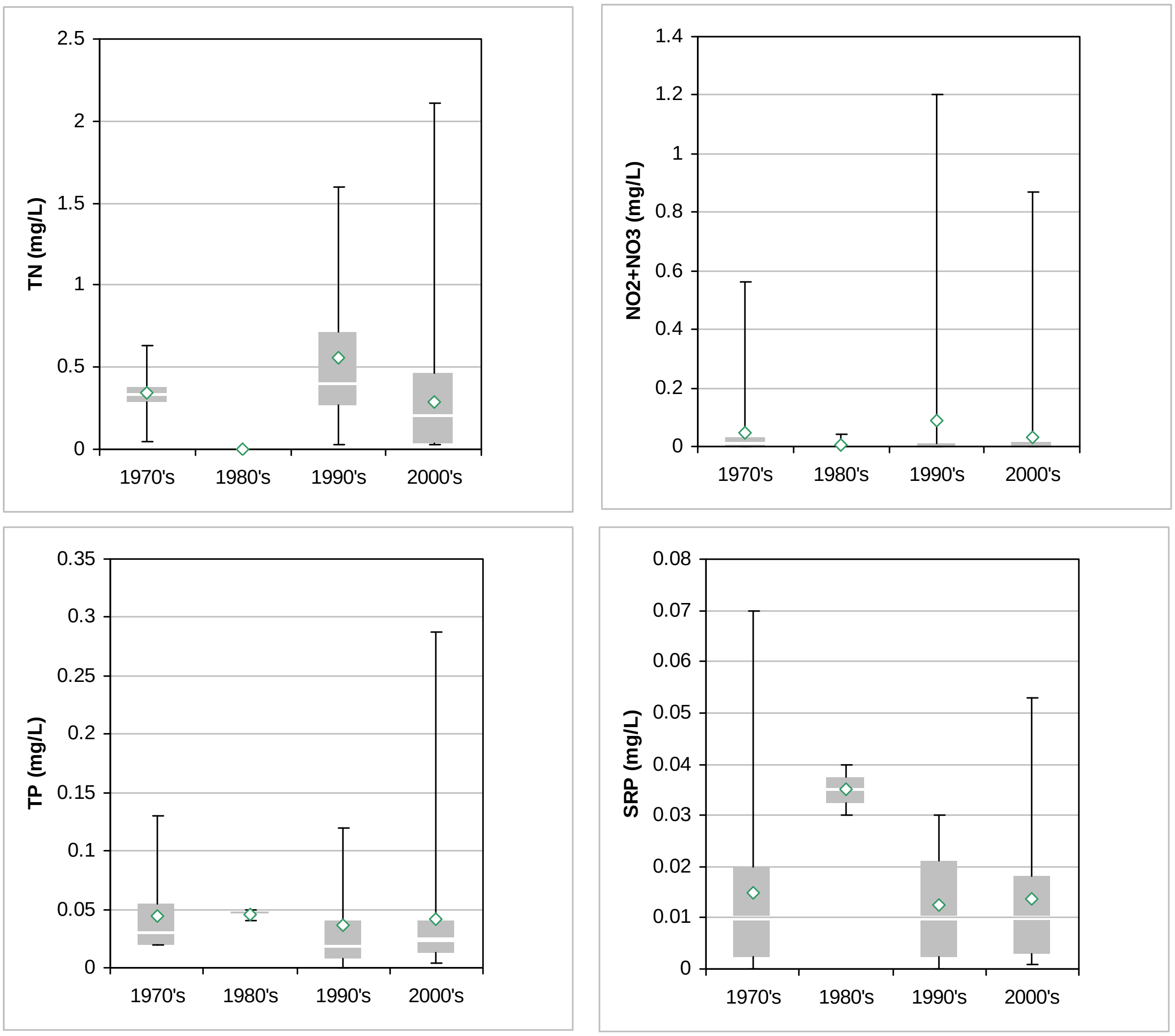


Figure 5. Box and whisker plots showing mean (e.g. green dot), median, quartiles, and ranges of total nitrogen (TN), dissolved nitrogen (NO2+NO3), total phosphorus (TP), and dissolved phosphorus (SRP) data collected in the Big Hole River watershed from 1970-current. Information originates from the STORET database.

Note: Number of observations during each decade shown below

Species	1970's	1980's	1990's	2000's
TN	10	0	11	219
NO2+NO3	18	62	15	189
TP	11	2	15	188
SRP	50	2	6	57

SECTION 4.0
MODELING APPROACH

From review of the data assessment, it was found that suitable data are available for development of a GWLF model of the Big Hole River watershed. The USGS database contains the necessary paired flow and chemistry data for calibration and validation, while observations from STORET can be used to fill data gaps (such as dissolved to total nutrient ratios and anticipated mean concentrations for TP, SRP, TN, and NO2+NO3). Thus the modeling project was initiated. A parameter transfer approach was used in the model development phase where calibration was completed on USGS 0601000 Big Hole River near Melrose, while a separate validation model was developed for a watershed similar in size to the TMDL watersheds, e.g. USGS 6025800 Willow Creek near Melrose. Attributes of each of the simulated watersheds are shown in **Table 5.**

Table 5. Characteristics of calibration and validation sites for GWLF modeling effort.

USGS No.	Site Name	Area (km2)	Forested Area (%)	Mean Elev. (m)	Mean Prcp (cm)
6025800	Willow Creek near Glen MT	92.8	74.7	2,224	71.3
6025500	Big Hole River near Melrose MT	6,384	57.3	2,149	63.1

The location of the proposed calibration and validation watersheds, along with the nine watersheds where TMDL analysis will be completed are shown in **Figure 6**. GWLF model input development activities are described in the following section.

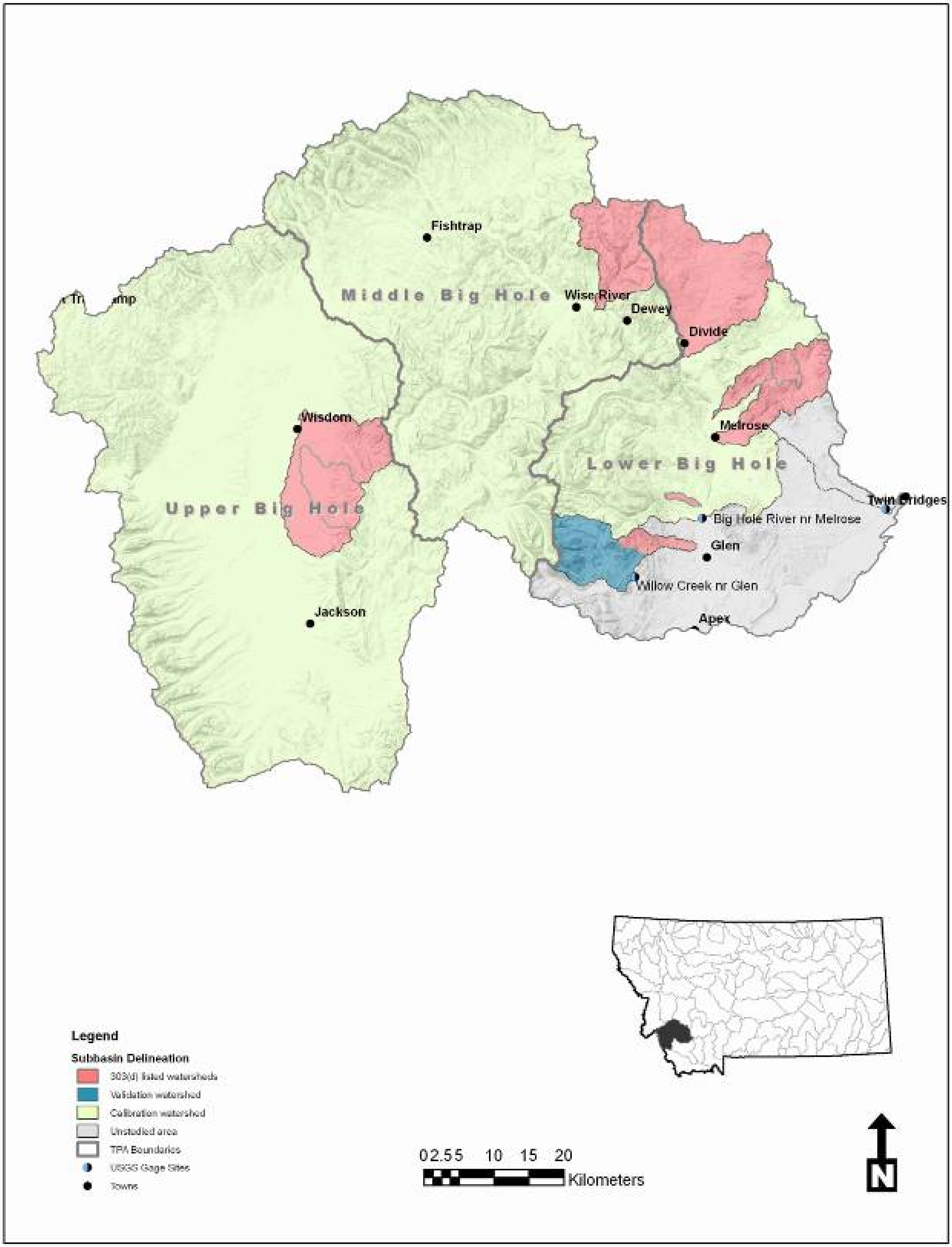


Figure 6. Map showing calibration and validation watersheds and 303(d) listed subbasins. The area in grey was not evaluated as part of the TMDL effort.

SECTION 5.0
GWLF MODEL DEVELOPMENT

5.1 GWLF Model Description

The Generalized Watershed Loading Functions model (GWLF) is a daily time-step model used in prediction of runoff, sediment, nitrogen, and phosphorus loads in variable sized watersheds. Rainfall, snowmelt, evapotranspiration, infiltration, dissolved and solid phase nutrient loading, and streambank erosion are all simulated as part of the model. It was written with the express purpose of requiring no calibration, and the model simply aggregates loads from each of the source areas in the watershed to form the overall pollutant load. The model is not spatially explicit and contains no routing component, therefore the complexity falls between that of detailed, process based simulation models and simple export coefficient models. GWLF has been endorsed by the U.S. EPA as a good “mid-level” model for simulating most of the key mechanisms controlling nutrient fluxes within a watershed (U.S. EPA, 1999).

5.2 GIS Pre-processing

The ArcView3.2 AVGWLF Geographic Information System (GIS) interface (Evans et al., 2002) was used to expedite the initial model setup and parameterization of GWLF. Fundamental input data for AVGWLF are topography (e.g. digital elevation model; DEM), land use/landcover (LULC), soils information, and climate. GIS data sources used in the Big Hole River GWLF model include:

- National Elevation Dataset (NED) – The USGS NED is a 1:24,000 scale DEM is used in calculation the slope length/steepness for the Universal Soil Loss Equation (USLE.) The BASINS version of the NED was used (USEPA, 2004).
- National Hydrography Dataset (NHD) – NHD is a 1:24,000 scale vector coverage of stream topology and was also taken from BASINS (USEPA, 2004). It was used as a definition of the channel network subject to bank erosion in the model.
- National Land Cover Dataset (NLDC) –NLCD (Homer et al., 2001) is a 29- category land cover classification (30-m grid) available over the conterminous U.S. It was used to develop gridded landcover inputs for runoff and erosion computations. (**Figure 7**)
- STATSGO Soils – The STATSGO soil map (NRCS, 1994) is a 1:250,000 scale generalization of detailed soil survey data that was used to develop soil erosion properties and associated information for runoff and erosion calculations.

5.3 Climate Input

Climate input for GWLF was based on Wisdom cooperative observer (COOP) station 249067, with adjustment for orographic precipitation and temperature variation using the Parameter-elevation Regressions on Independent Slopes Model (PRISM) (Daily et al., 2000), and environmental lapse rate. The annual ratio between the site data, and that of the watershed being modeled, was used in this adjustment. PRISM data was taken directly from the Montana Natural

Resource Information System (NRIS, 2008), and the environmental lapse rate from the International Civil Aviation Organization (ICAO, 2008) was used.

5.4 Water Balance/Hydrologic Input

Hydrology in GWLF is partitioned into surface water and groundwater components using the SCS-curve number (CN) methodology. Curve number estimation procedures are described below.

5.4.1 Curve Number Estimation

Curve number was estimated using the combination of the National Land Cover Dataset (NLCD; Homer et al., 2001) and STATSO soil database (NRCS, 1994). Six aggregated source categories were used in facilitating the modeling including: water, developed, forest, grassland, shrub/scrub (e.g. sagebrush), and pasture/hay. They are shown in **Table 6**. Of these, forest, grassland, and shrubland comprise over 90 percent of the total watershed area (43.9 percent, 34.3 percent, and 14.0 percent respectively). The remaining portions include open water (0.3 percent), developed lands (1.5 percent), and pasture/hay (5.8 percent). Curve numbers derived for each of these land classes are shown in **Table 7**.

Table 6. Landcover and aggregated land classes used in the GWLF modeling (original source, NLCD 2001).

NLCD 2001 Landcover	Area (hectares)[2]	Percentage (%)	GWLF-E Re-classified Landcover
Open Water	1,141	0.2%	Open Water
Perennial Ice, Snow	49	0.0%	
Developed, Open Space	4,604	0.6%	Developed
Developed, Low Intensity	1,235	0.2%	
Developed, Medium Intensity	190	0.0%	
Developed, High Intensity	4	0.0%	
Barren Land, Rock	3,739	0.5%	Forest
Deciduous Forest	341	0.0%	
Evergreen Forest	378,881	52.1%	
Mixed Forest	98	0.0%	
Woody Wetlands	1,942	0.3%	
Emergent Herbaceous Wetlands	43	0.0%	
Shrub, Scrub	37,888	5.2%	Shrub, Scrub
Grassland, Herbaceous	273,009	37.5%	Grassland, Herbaceous
Pasture/Hay	21,157	2.9%	Pasture/Hay
Cultivated Crops (1)	2,963	0.4%	

1 Review of aerial photographs and NLCD 2001 indicate that cultivated crops typically consist of alfalfa and/ or hay.
2 Areas for entire watershed; not be confused with areas used in modeling.

Table 7. Curve numbers used in GWLF modeling.

GWLF-E Re-classified Land Class	Dominant Hydrologic Soil Group	Curve Number AMC II
Developed	B	70
Evergreen Forest	A	45
Shrub, Scrub	B	49
Grassland, Herbaceous	B	62
Pasture/Hay	B	58

5.4.2 Irrigation

Irrigation was accounted for in GWLF using crop evapotranspiration (ET) from the Dillon (DLNM) AGRIMET site and associated crop area. Losses of 25 percent were assumed to occur in the distribution system. Estimated withdrawls were then directly subtracted from the overall “streamflow” component of the water balance with the provision that the diverted value did not exceed simulated streamflow (e.g. no negative streamflow calculations). The calculation procedure for this methodology is shown in the **Appendix A1**.

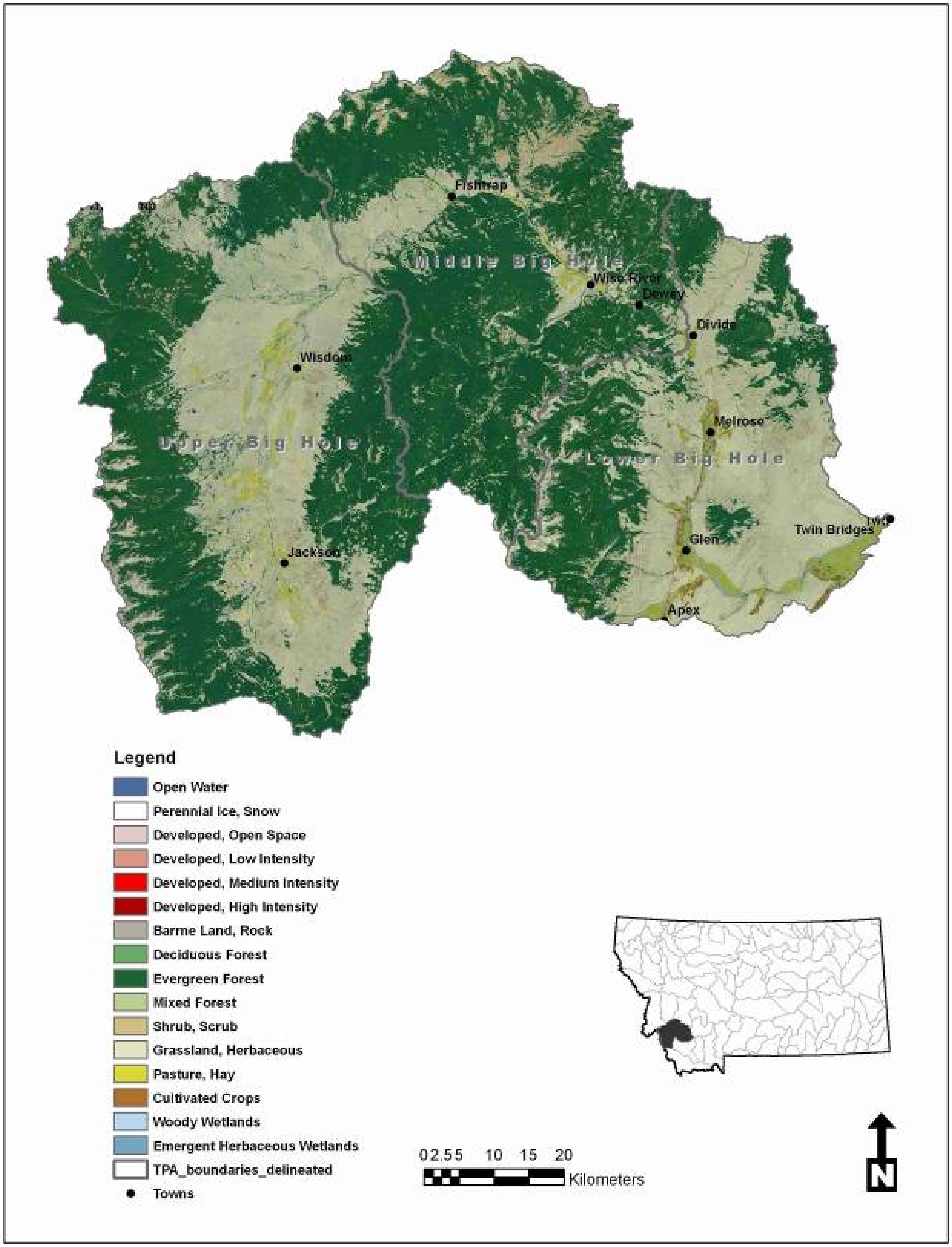


Figure 7. Landcover of the Big Hole River watershed (Homer, et al., 2001).

5.5 Sediment Input

5.5.1 Hillslope Erosion

Erosion and sedimentation are computed in GWLF using the Universal Soil Loss equation (USLE). Input parameters used in the GWLF modeling are shown in **Table 8** and are consistent with studies conducted elsewhere by DEQ.

Table 8. USLE parameter assignment for GWLF modeling.

USLE Assignment[1,2]					**Assignment Details**		
GWLF-E Re-classified Land Class	**[3]K-Factor**	**[4]LS-Factor**	**[5]C-factor**	**[6]P-factor**	**Ground or canopy Cover**	**Canopy Type**	**Cover Type**
Developed	WS	WS	0.09	1	---	none	G/W
Evergreen Forest	WS	WS	0.003	1	---	forest	60% duff
Shrub, Scrub	WS	WS	0.05	1	---	20" brush	G
Grassland, Herbaceous	WS	WS	0.07	1	---	none	G
Pasture/Hay	WS	WS	0.02	1	---	none	G

[1] WS = Watershed specific; computed from GIS layers
[2] Rainfall erosivity factor calculated from daily precipitation
[3] Soil erodibility factor from NRCS STATSGO grid
[4] Topographic factor calculated from Basins DEM
[5] Cover management factor from Brooks, 1999 and MCcuen, 1998
[6] P-factor of unity applied (e.g. no conservation practices)

5.5.1 Streambank Erosion

Streambank erosion is computed within GWLF using a rating curve approach. Parameterization of the lateral bank erosion "a" coefficient was completed solely through model calibration. In order to properly scale parameters for watersheds with differing streamflow conditions, "a" was adjusted to maintain a consistent lateral erosion rate for each watershed (e.g. to maintain the rate determined in the calibration). Coefficients used in the modeling are shown in the model input in the **Appendix A3**.

5.6 Nutrient Input

5.6.1 Dissolved Nutrients

Dissolved nutrients in GWLF are simulated using event mean concentrations (EMCs). Those coefficients used in the modeling were fine-tuned through model calibration (**Table 9**) and were in agreement with the literature (see Haith et al., 1992; USEPA, 1983; USEPA, 2001). Dissolved nutrient concentrations in groundwater were based on the land use with the most subsurface water yield, which for the most part, was from forested areas. Thus the EMC for forest surface runoff was applied to dissolved groundwater (e.g. 0.05 and 0.02 mg/L N and P) and appeared to yield the best results during model calibration.

Table 9. EMC parameters used in GWLF model.

Land Use	Dissolved Nitrogen (mg/L)	Dissolved Phosphorus (mg/L)
Developed (kg/ha/day)	0.012	0.002
Evergreen Forest	0.05	0.02
Shrub, Scrub	0.5	0.1
Grassland, Herbaceous	0.5	0.1
Pasture/Hay	3.5	0.25

5.6.2 Organic/Solid Phase Nutrients

Solid phase nutrients in GWLF originate from landscape and streambank based soil erosion. Since watershed specific information was not available regarding soil nutrient concentrations, values were taken from the national map provided in the GWLF user’s manual. A value of 1500 mg/kg was used for nitrogen and 620 mg/kg for phosphorus. During calibration, it was found that GWLF was unable to account a large organic load from forested environments. Therefore, an organic load component was added to the model using the computed forest water yield and an associated concentration of organic nitrogen and phosphorus observed in forest surface runoff (0.24 and 0.017 mg/L of nitrogen and phosphorus respectively). This modification brought the balance of dissolved nutrient to total nutrient ratios into much closer alignment.

5.6.3 Non-Recoverable Animal Manure

Non-recoverable animal manure loads were estimated in GWLF using livestock density data from the U.S. Agricultural Statistics Service (NASS, 2008) and an associated delivery ratio to surface waters. Manure composition taken directly from the Animal Waste Management, National Engineering Handbook (NRCS, 1999) and an adjustment procedure was used to correct the number of reported animals to actual animal units (AU). Delivery ratio of nutrient loads from animal manure was based entirely on the literature (see Pieterse et al., 2003; Johnes, 1996; De Wite, 2000; Johnson et al., 1976; and Olness et al., 1980) and a value of 5 percent for nitrogen, and 0.01 percent for phosphorus were used in the modeling. More information on the farm animal manure calculations can be found in the Appendix.

5.6.4 Septic Systems

Septic system loads were crudely estimated using aerial imagery (2005 NAIP) and data from the STEPL Model Input Data Server which provides coarse, regional level information about per capita tank use and failure rates from the National Environmental Service Center (1992). Estimated septic densities for each of the watersheds are shown in the Appendix, and are considered approximations only.

5.7 Model Calibration-Validation

The general approach toward GWLF calibration and validation, was typical of that of any watershed modeling endeavor: (1) calibration of monthly streamflow, (2) sediment calibration, and then (3) nutrient calibration. Calibrated reach parameters are shown in Attachment-A, and are based on user experience, knowledge of the watershed, and recommendations from the GWLF user's manual. Those used in the calibration include SCS curve number, evapotranspiration coefficient, saturated and unsaturated aquifer parameters, groundwater recession constant, deep aquifer/seepage coefficient, monthly rainfall erosivity coefficient, streambank sediment coefficient, event mean concentrations (EMCs), and groundwater nutrient EMCs.

5.8 Model Evaluation Criteria

Performance statistics were selected prior to model development to assess monthly and seasonal streamflow, sediment, and nutrient predictions from GWLF. The first criterion used in the project was percent bias (PBIAS), which is a measure of the average tendency of the simulated temperatures to be larger or smaller than an observed value. Optimal PBIAS is 0.0 while a positive value indicates a model bias toward overestimation. A negative value indicates bias toward underestimation. PBIAS is calculated as follows:

$$PBIAS = \frac{\sum_{i=1}^{n}(O_{isim} - O_{iobs})}{\sum_{i=1}^{n}(O_{iobs})} \times 100$$

Equation 1

where

PBIAS = deviation in percent
Tiobs = observed value
Tisim = simulated value

DEQ defined acceptable model bias for the Big Hole River GWLF model as ±15 percent, similar to that reported in the literature by Van Liew et al. (2005) and Donigian et al. (1983). The second evaluation criterion was the Nash-Sutcliffe coefficient of efficiency (NSE; Nash and Sutcliffe, 1970). NSE expresses the fraction of the measured variance that is reproduced by the model. As error in the model is reduced, the NSE coefficient is inherently increased. Simulation results are considered to be good for NSE > 0.75, while values between 0.36 and 0.75 are considered satisfactory (Motovilov et al. 1999). NSE is calculated as:

$$NS_E = 1 - \frac{\sum_{i=1}^{n}(O_{iobs} - O_{isim})^2}{\sum_{i=1}^{n}(O_{iobs} - O_{avg})^2}$$

Equation 2

where

NSE = coefficient of efficiency
Tavg = average simulated value

Reported statistics for calibration and validation of each of the measures shown previously are shown in **Section 6.0**.

5.9 Model Sensitivity/Uncertainty

Given the “limited-detail” nature of this study, model sensitivity and uncertainty were not addressed as part of this project. To some extent, model uncertainty can be characterized by review of the results and discussion section. It is recommended that a margin of safety (MOS) be built into the TMDL to account for this inherent error.

SECTION 6.0 RESULTS AND DISCUSSION

6.1 Water Balance/Hydrology

6.1.1 Calibration

Monthly streamflow for the calibration is shown in **Figure 8**. Inspection of the observed and predicted values shows satisfactory agreement. In general, the model predicts growing season streamflow values very well (May-September), while predictions during the winter months are poor. This largely is due to the inability to lag groundwater from month to month. Snowmelt appears to be accurately represented based on the rising limb of the hydrograph, and the falling limb is also well simulated. PBIAS and NSE were +1.1 percent and 0.69 respectively (**Table 10**).

6.1.2 Validation

Results of the hydrologic validation on Willow Creek (a gaged tributary similar in size to the TMDL watersheds) are only slightly different from the calibration. PBIAS and NSE were +8.9 percent and 0.58 (**Figure 9**) which largely demonstrates that the parameter transfer approach is effective for hydrologic predictions for the remaining TMDL watersheds.

Table 10. Summary of calibration and validation statistics from Big Hole River GWLF model.

Watershed	Hydrology		Sediment[1]		Nutrients	
	NSE	PBIAS	NSE	PBIAS	NSE	PBIAS
Big Hole River near Melrose, MT (calibration)	0.69	+1.1%	0.54	+0.4%	0.56	+0.7%
Willow Creek near Glen, MT (validation)	0.58	+8.9%	-4.61	+145.6%	0.39	-8.7%

[1]Validation much better than reported if two outlier peaks removed; NSE = 0.54 and PBIAS = +21.2%.

6.2 Sediment

6.2.1 Calibration

PBIAS and NSE for the sediment calibration were +0.4 percent and 0.54 respectively (**Figure 8**). Sediment peaks generally follow hydrograph response, and a majority of the sediment load in the watershed occurs during the months of May, June, and July. Based on the modeling results, the source of this load is primarily streambank erosion. Several false peaks do occur, and are likely a result of spatial variability in precipitation. Overpredictions are consistent with oversimulated peaks in hydrology.

6.2.2 Validation

Analysis of the validation model show very poor results. PBIAS and NSE were +145.6 percent and 4.61 (**Figure 9**). This is largely as a result of two vastly over-simulated sediment peaks in the months of 10/1963 and 6/1964. Again, these are likely a function of precipitation variability in the watershed and predictions would be much better in the absence of these peaks (i.e. PBIAS of +21.2 percent and NSE of 0.54). Fortunately, errors in sediment simulation have only minor impacts on simulated organic nitrogen and phosphorus loads. Thus it is believed that the use of GWLF for TMDL planning is still valid.

6.3 Nutrients

6.3.1 Calibration

Calibration of the nutrients was inherently uncertain, as many of the nutrient species were not measured at the USGS gage sites. Because of this, the model was first calibrated to observed USGS dissolved nitrogen data (e.g. measured NO3-), and then a quasi-calibration was completed to fit the remaining species to mean concentration and dissolved to total nutrients ratios observed in STORET. PBIAS and NSE for the NO3- calibration was +0.7 percent and 0.56 (**Table 10**) while simulated and observed dissolved nitrogen and phosphorus concentrations and ratios are shown in **Table 11**.

6.3.2 Validation

The validation performed similar to the calibration, with PBIAS and NSE of -8.7 percent and 0.39. Validation concentrations and statistics are shown in **Table 11**. Clearly, nutrient simulations are adequate for low certainty TMDL planning.

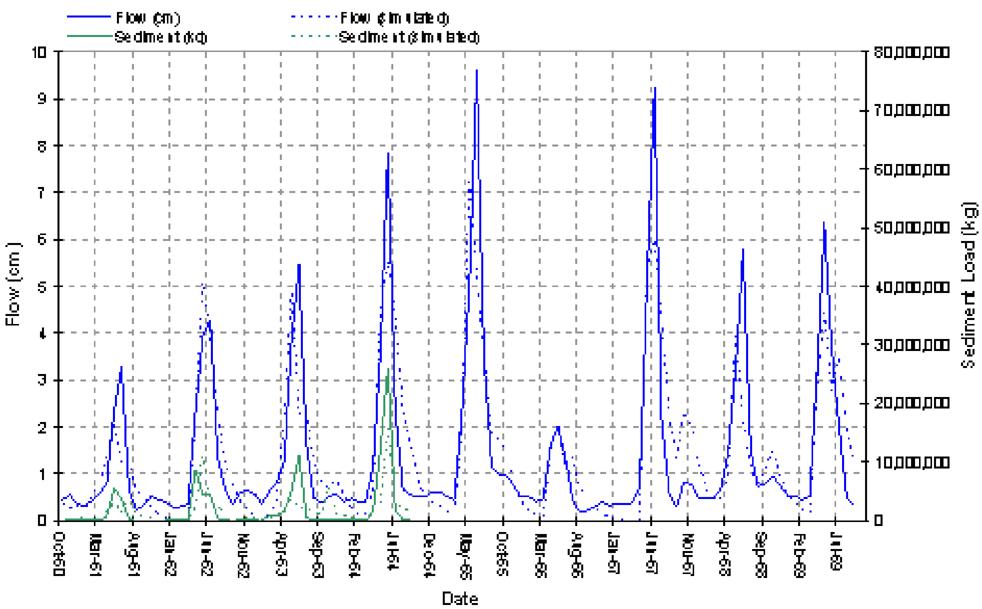
Table 11. Summary of observed and simulated mean concentrations and dissolved nutrient ratios in the Big Hole River GWLF model.

Watershed	Nitrogen			Phosphorus		
	TN (mg/L)	NO2+ NO3 (mg/L)	Dissolved: Total ratio	TP (mg/L)	SRP (mg/L)	Dissolved : Total ratio
STORET – all observations	0.31	0.03	0.10	0.041	0.014	0.34
Big Hole River near Melrose, MT (calibration)	0.28	0.08	0.29	0.049	0.026	0.53
Willow Creek near Glen, MT (validation)	0.27	0.06	0.22	0.046	0.022	0.48
Reference Non-reference from Suplee et al. (2007)	0.22 0.40	0.02 0.10	0.09 0.25	0.01 0.04	0.005 0.020	0.50 0.50

6.4 Summary

Given that hydrology, sediment, and nutrients are adequately simulated in GWLF, TMDL development activities for impaired water bodies in the Big Hole River watershed were initiated and area detailed in subsequent sections.

a) Calibration



b) Validation

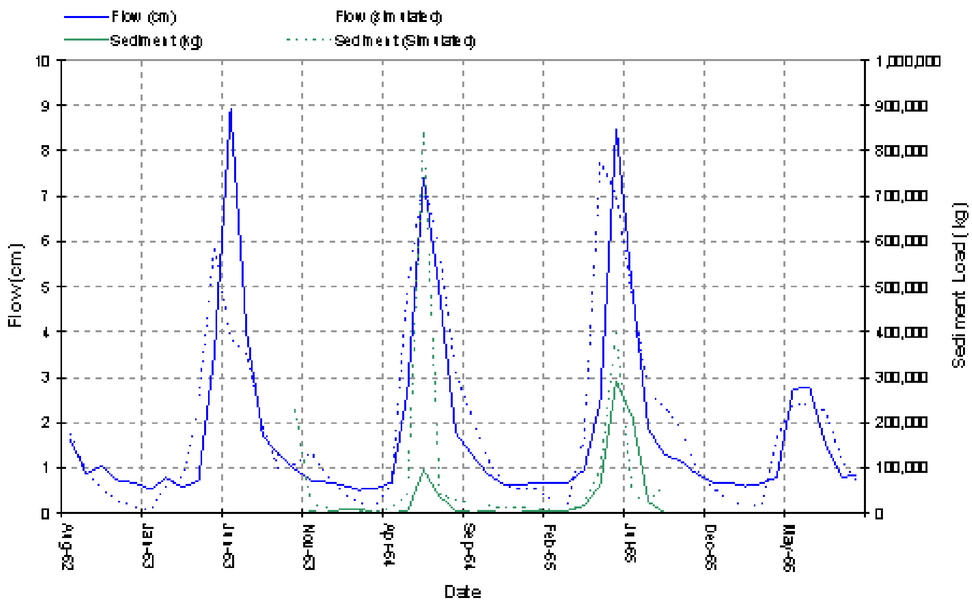


Figure 8. Calibration and validation plots for sediment and hydrology for a) USGS gage 6025500 Big Hole River near Melrose, MT and b) USGS gage 6025800 Willow Creek near Glen MT.

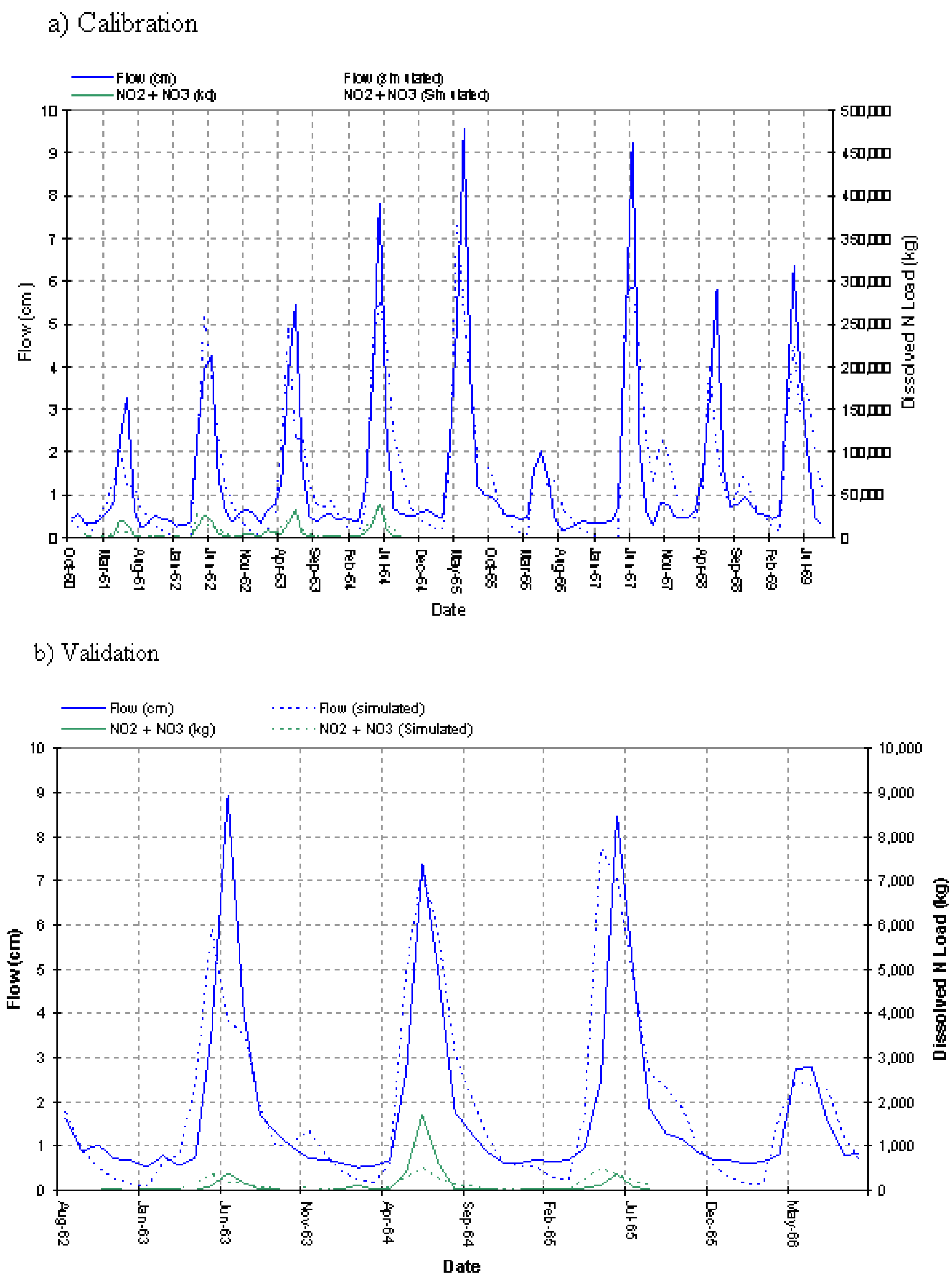


Figure 9. Calibration and validation plots for nutrients and hydrology for a) USGS gage 6025500 Big Hole River near Melrose, MT and b) USGS gage 6025800 Willow Creek near Glen MT.

SECTION 7.0
TMDL SOURCE ASSESSMENT

Following validation of the modeling approach, source estimates for the TMDL watersheds were completed over a representative period for which the data were compiled (24 years). A summary of the predicted annual nitrogen and phosphorus source contributions for each of the TMDL watersheds are shown in **Figure 10** and **Figure 11**. Simulated sources include: (1) hay/pasture (including fertilizer application and grazing), (2) shrub and grassland (with effects of grazing), (3) forested areas (including grazing), (4) developed areas (including both urban runoff and septic effluent), and (5) streambanks. Non-recoverable animal manure from each land use was lumped into its specific source category based on the estimated percentage cattle were on each land cover type (e.g. on hay/pasture 20 percent of the time, grassland/shrub 60 percent, and forest 20 percent). Individual source assessments for each of the TMDL watersheds are shown in **Figures 12-20** and **Tables 10-18**.

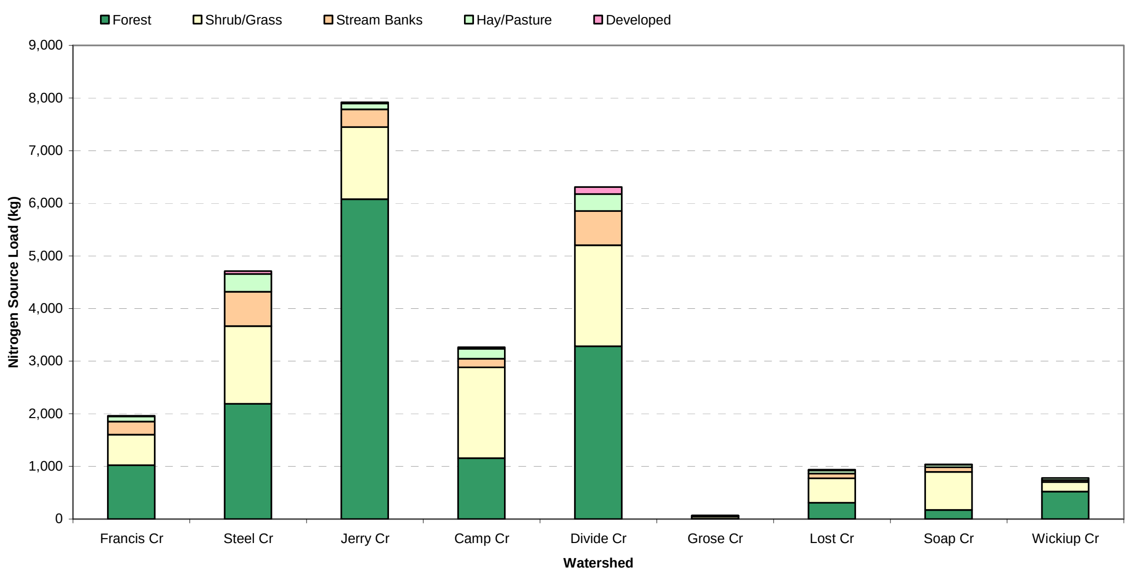


Figure 10. Summary of estimated nitrogen sources in each TMDL watershed.

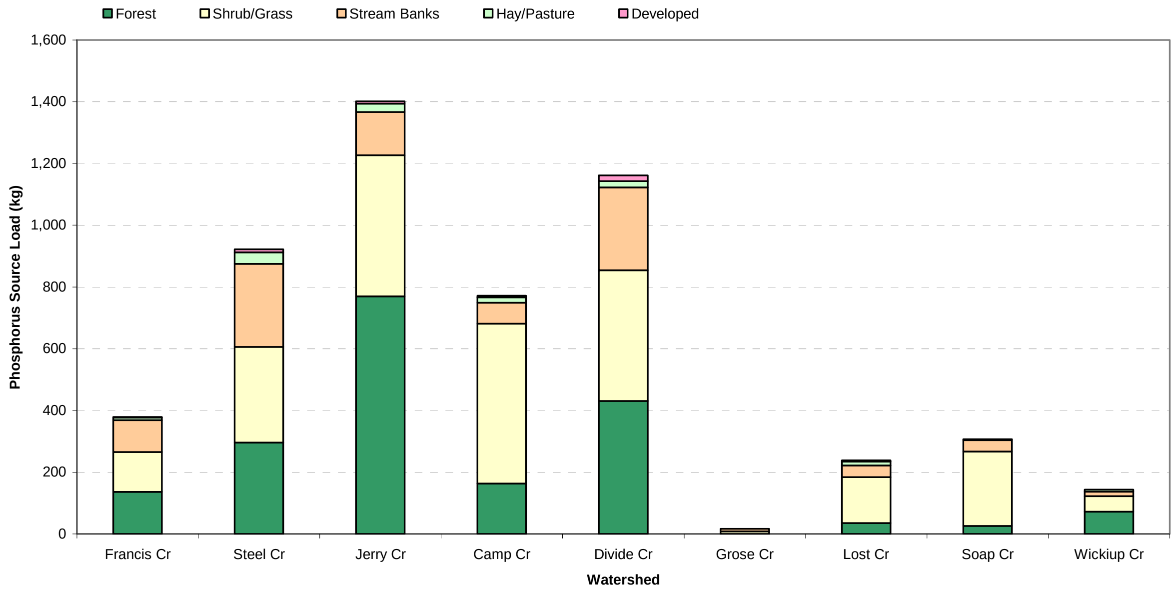
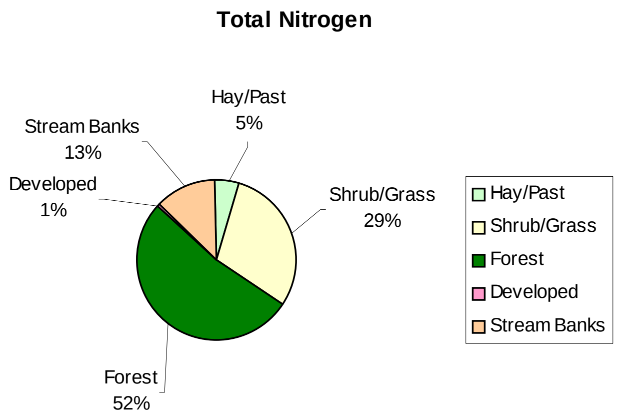


Figure 11. Summary of estimated phosphorus sources in each TMDL watershed.

7.1 Francis Creek

The existing condition source assessment for Francis Creek is shown below (**Figure 12**, **Table 12**).



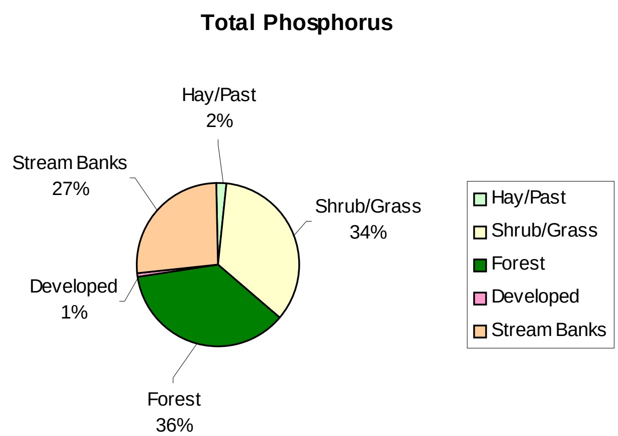


Figure 12. Graphical Nutrient Source Assessment for Francis Creek.

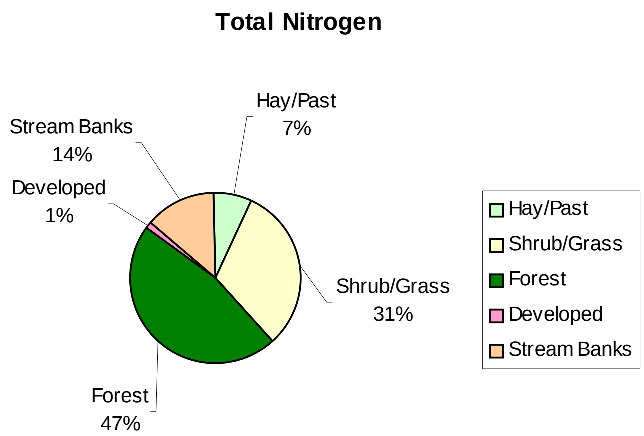
Table 12. Tabular Nutrient Source Assessment for Francis Creek.

Source	**Area (ha)**	**Runoff (cm)**	**Sediment (kg x 1000)**	**Dis N (kg)**	**Tot N (kg)**	**Dis P (kg)**	**Tot P (kg)**
Hay/Past	130	0.39	0.40	13.7	99.3	1.8	8.4
Shrub/Grass	3311	0.76	86.36	104.6	578.2	69.2	129.1
Forest	3036	0.05	20.75	0.8	1024.5	13.2	136.5
Developed	35	1.59	0.56	0.0	11.1	0.0	2.3
Stream Banks			166.06	0.0	249.1	0.0	103.0
Point Source			0.00	0.0	0.0	0.0	0.0
Groundwater[1]			0.00	0.0	0.0	0.0	0.0

[1]Groundwater load integrated into landscape source categories based on computed runoff (e.g. surrogate for infiltration/groundwater recharge)

7.2 Steel Creek

The existing condition source assessment for Steel Creek is shown below (**Figure 13**, **Table 13**).



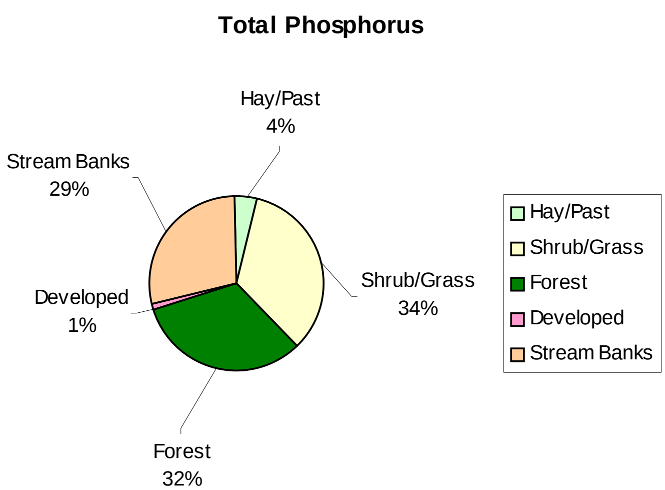


Figure 13. Graphical Nutrient Source Assessment for Steel Creek.

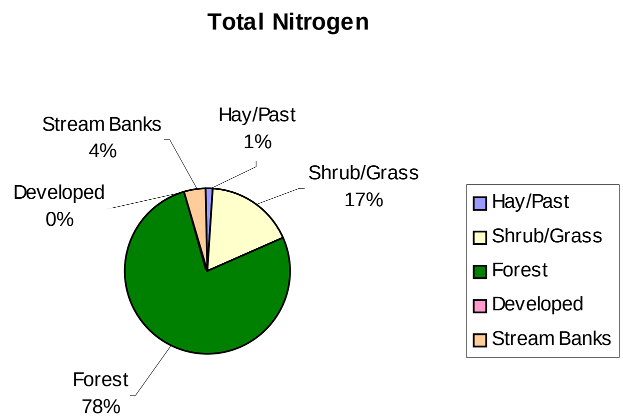
Table 13. Tabular Nutrient Source Assessment for Steel Creek.

Source	Area (ha)	Runoff (cm)	Sediment (kg x 1000)	Dis N (kg)	Tot N (kg)	Dis P (kg)	Tot P (kg)
Hay/Past	828	0.52	1.75	108.6	338.7	15.7	37.2
Shrub/Grass	8610	0.97	152.76	352.1	1474.0	148.5	309.8
Forest	6008	0.06	34.87	1.7	2192.4	22.3	296.3
Developed	192	1.97	2.02	0.0	57.5	0.0	9.5
Stream Banks			434.22	0.0	651.3	0.0	269.2
Point Source			0.00	0.0	0.0	0.0	0.0
Groundwater[1]			0.00	0.0	0.0	0.0	0.0

[1]Groundwater load integrated into landscape source categories based on computed runoff (e.g. surrogate for infiltration/groundwater recharge)

7.3 Jerry Creek

The existing condition source assessment for Jerry Creek is shown below (**Figure 14**, **Table 14**).



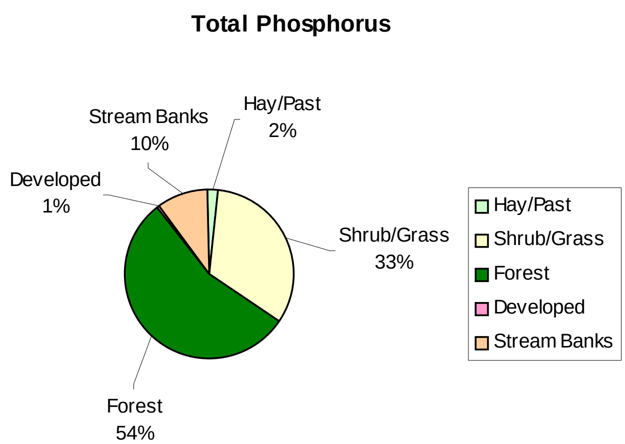


Figure 14. Graphical Nutrient Source Assessment for Jerry Creek.

Table 14. Tabular Nutrient Source Assessment for Jerry Creek.

Source	**Area (ha)**	**Runoff (cm)**	**Sediment (kg x 1000)**	**Dis N (kg)**	**Tot N (kg)**	**Dis P (kg)**	**Tot P (kg)**
Hay/Past	29	1.68	0.07	13.0	114.5	1.7	27.0
Shrub/Grass	2106	3.08	447.67	250.8	1370.6	130.7	457.0
Forest	9741	0.32	121.02	15.6	6076.3	81.3	770.2
Developed	1	5.09	0.01	0.0	21.2	0.0	8.2
Stream Banks			224.97	0.0	337.5	0.0	139.5
Point Source			0.00	0.0	0.0	0.0	0.0
Groundwater[1]			0.00	0.0	0.0	0.0	0.0

[1]Groundwater load integrated into landscape source categories based on computed runoff (e.g. surrogate for infiltration/groundwater recharge)

7.4 Camp Creek

The existing condition source assessment for Camp Creek is shown below (**Figure 15**, **Table 15**).

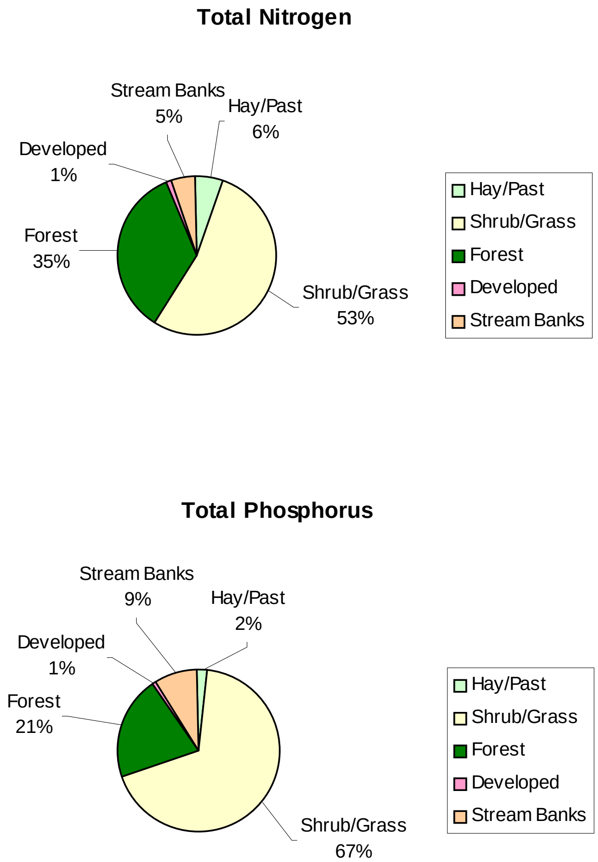


Figure 15. Graphical Nutrient Source Assessment for Camp Creek.

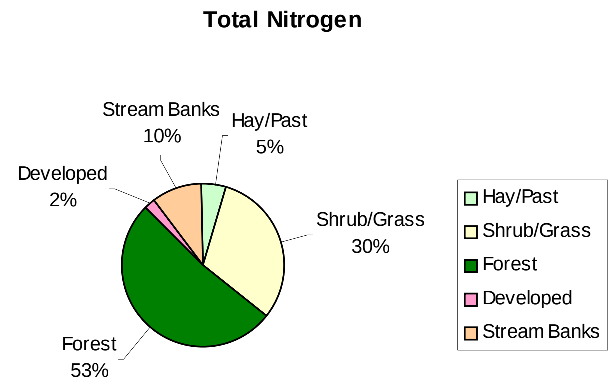
Table 15. Tabular Nutrient Source Assessment for Camp Creek.

Source	**Area (ha)**	**Runoff (cm)**	**Sediment (kg x 1000)**	**Dis N (kg)**	**Tot N (kg)**	**Dis P (kg)**	**Tot P (kg)**
Hay/Past	315	0.53	0.52	43.4	186.9	6.0	17.7
Shrub/Grass	5684	0.99	601.92	230.8	1725.5	300.7	517.9
Forest	2784	0.07	28.46	0.9	1157.4	18.0	163.3
Developed	95	1.99	0.80	0.0	31.3	0.0	5.4
Stream Banks			109.54	0.0	164.3	0.0	67.9
Point Source			0.00	0.0	0.0	0.0	0.0
Groundwater[1]			0.00	0.0	0.0	0.0	0.0

[1]Groundwater load integrated into landscape source categories based on computed runoff (e.g. surrogate for infiltration/groundwater recharge).

7.5 Divide Creek

The existing condition source assessment for Divide Creek is shown below (**Figure 16**, **Table 16**).



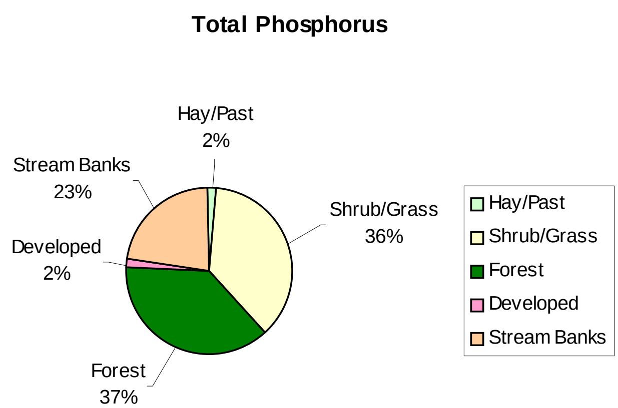


Figure 16. Graphical Nutrient Source Assessment for Divide Creek.

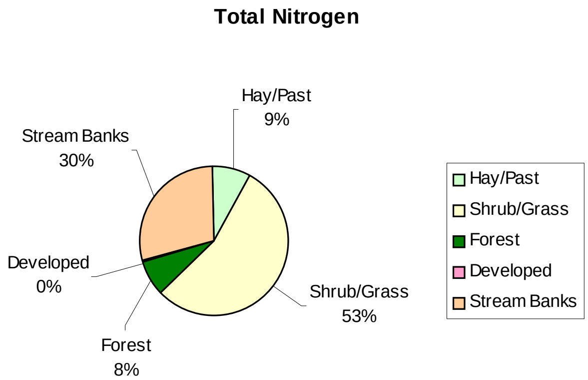
Table 16. Tabular Nutrient Source Assessment for Divide Creek.

Source	Area (ha)	Runoff (cm)	Sediment (kg x 1000)	Dis N (kg)	Tot N (kg)	Dis P (kg)	Tot P (kg)
Hay/Past	496	0.24	0.58	33.6	324.0	4.1	20.0
Shrub/Grass	11845	0.48	341.79	250.0	1918.1	255.2	423.4
Forest	11622	0.02	44.09	1.3	3283.6	27.9	430.7
Developed	598	1.18	8.08	0.0	130.6	0.0	18.3
Stream Banks			433.73	0.0	650.6	0.0	268.9
Point Source			0.00	0.0	0.0	0.0	0.0
Groundwater[1]			0.00	0.0	0.0	0.0	0.0

[1]Groundwater load integrated into landscape source categories based on computed runoff (e.g. surrogate for infiltration/groundwater recharge)

7.6 Grose Creek

The existing condition source assessment for Grose Creek is shown below (**Figure 17**, **Table 17**).



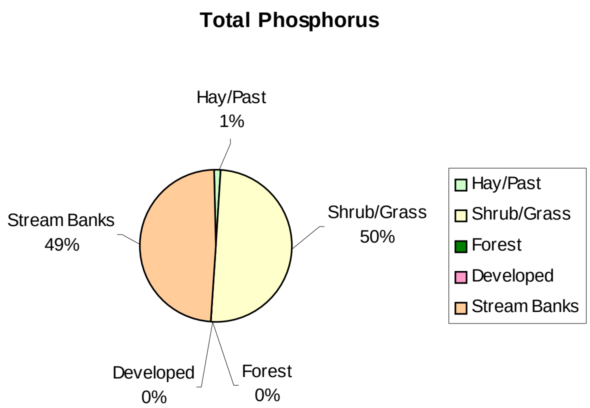


Figure 17. Graphical Nutrient Source Assessment for Grose Creek.

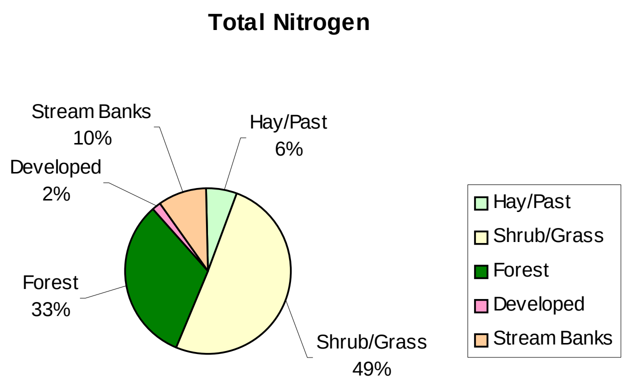
Table 17. Tabular Nutrient Source Assessment for Grose Creek.

Source	Area (ha)	Runoff (cm)	Sediment (kg x 1000)	Dis N (kg)	Tot N (kg)	Dis P (kg)	Tot P (kg)
Hay/Past	21	0.02	0.04	0.1	5.9	0.0	0.2
Shrub/Grass	393	0.05	12.61	0.9	36.3	8.0	8.3
Forest	1	0.00	0.00	0.0	5.3	0.0	0.0
Developed	4	0.20	0.04	0.0	0.2	0.0	0.0
Stream Banks			13.43	0.0	20.1	0.0	8.3
Point Source			0.00	0.0	0.0	0.0	0.0
Groundwater[1]			0.00	0.0	0.0	0.0	0.0

[1]Groundwater load integrated into landscape source categories based on computed runoff (e.g. surrogate for infiltration/groundwater recharge)

7.7 Lost Creek

The existing condition source assessment for Lost Creek is shown below (**Figure 18**, **Table 18**).



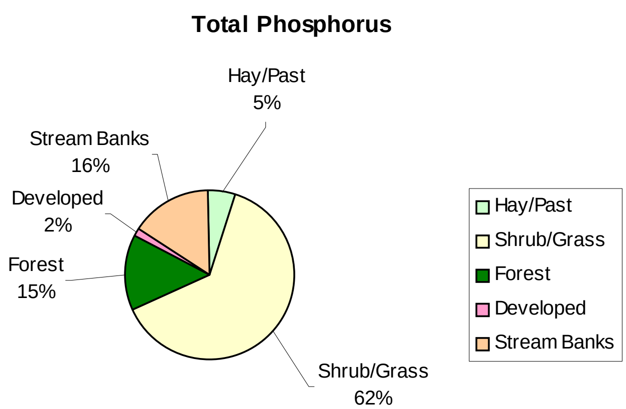


Figure 18. Graphical Nutrient Source Assessment for Lost Creek.

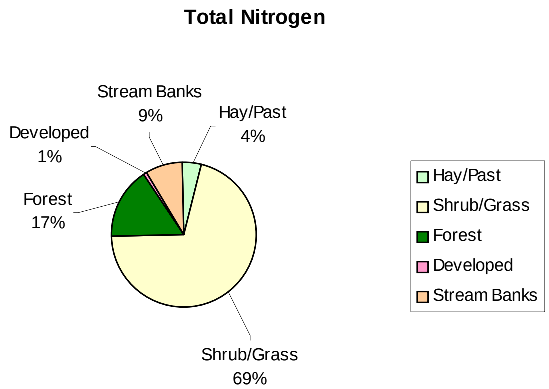
Table 18. Tabular Nutrient Source Assessment for Lost Creek.

Source	**Area (ha)**	**Runoff (cm)**	**Sediment (kg x 1000)**	**Dis N (kg)**	**Tot N (kg)**	**Dis P (kg)**	**Tot P (kg)**
Hay/Past	10	0.47	0.04	1.2	58.7	0.2	12.6
Shrub/Grass	1243	0.89	192.82	45.7	465.3	115.8	149.1
Forest	949	0.06	13.27	0.3	309.0	8.3	35.1
Developed	29	1.77	1.48	0.0	15.6	0.0	4.2
Stream Banks			60.58	0.0	90.9	0.0	37.6
Point Source			0.00	0.0	0.0	0.0	0.0
Groundwater1			0.00	0.0	0.0	0.0	0.0

[1]Groundwater load integrated into landscape source categories based on computed runoff (e.g. surrogate for infiltration/groundwater recharge).

7.8 Soap Creek

The existing condition source assessment for Soap Creek is shown below (**Figure 19, Table 19**).



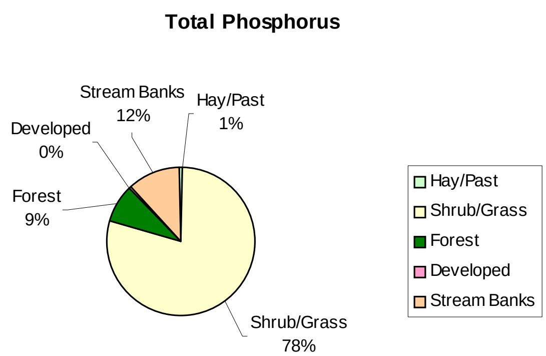


Figure 19. Graphical Nutrient Source Assessment for Soap Creek.

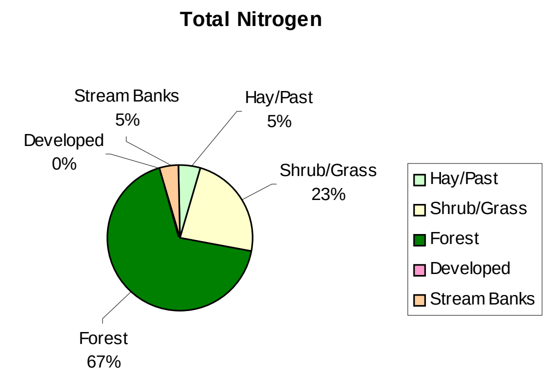
Table 19. Tabular Nutrient Source Assessment for Soap Creek.

Source	Area (ha)	Runoff (cm)	Sediment (kg x 1000)	Dis N (kg)	Tot N (kg)	Dis P (kg)	Tot P (kg)
Hay/Past	42	0.35	0.02	3.9	46.3	0.5	2.5
Shrub/Grass	1981	0.67	329.82	54.0	725.3	175.6	240.8
Forest	365	0.04	5.33	0.1	171.2	3.3	26.4
Developed	22	1.46	0.28	0.0	5.8	0.0	1.0
Stream Banks			58.93	0.0	88.4	0.0	36.5
Point Source			0.00	0.0	0.0	0.0	0.0
Groundwater[1]			0.00	0.0	0.0	0.0	0.0

[1]Groundwater load integrated into landscape source categories based on computed runoff (e.g. surrogate for infiltration/groundwater recharge)

7.9 Wickiup Creek

The existing condition source assessment for Wickiup Creek is shown below (**Figure 20, Table 20**).



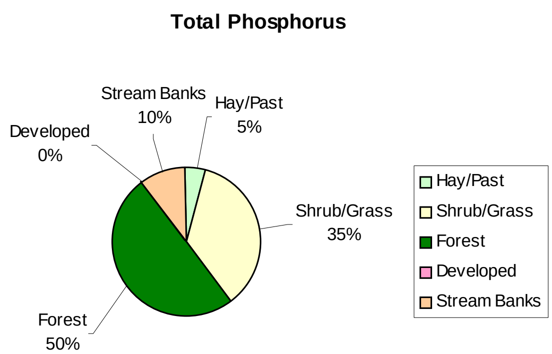


Figure 20. Graphical Nutrient Source Assessment for Wickiup Creek.

Table 20. Tabular Nutrient Source Assessment for Wickiup Creek.

Source	**Area (ha)**	**Runoff (cm)**	**Sediment (kg x 1000)**	**Dis N (kg)**	**Tot N (kg)**	**Dis P (kg)**	**Tot P (kg)**
Hay/Past	56	0.95	2.08	13.9	38.2	1.9	6.6
Shrub/Grass	505	1.50	53.39	37.9	180.4	40.7	50.4
Forest	1034	0.11	8.16	0.6	523.0	5.3	72.0
Developed	0	0.00	0.00	0.0	0.0	0.0	0.0
Stream Banks			23.54	0.0	35.3	0.0	14.6
Point Source			0.00	0.0	0.0	0.0	0.0
Groundwater[1]			0.00	0.0	0.0	0.0	0.0

[1]Groundwater load integrated into landscape source categories based on computed runoff (e.g. surrogate for infiltration/groundwater recharge).

7.10 Summary of TMDL Source Assessment Results

In review of the existing condition source assessment, nitrogen and phosphorus loads are a function of land cover type, soils, topography, and associated land management practices. For the most part, forest and shrub/grassland provide the largest natural loads in the TMDL watersheds while anthropogenic sources are primarily of agricultural origin. Those loads consist of non-recoverable animal manure, grazing, and fertilization of hay/pasture, along with minor contributions from developed lands. Streambanks were also found to contribute a moderate amount of nitrogen and phosphorus to TMDL watersheds. In any case, existing loads for each of the impaired watersheds were estimated. **Section 8.0** details scenarios that evaluate mitigation measures for significant and controllable sources.

SECTION 8.0
SCENARIO ANALYSIS

Following the estimation of existing condition sources, a number of scenarios were evaluated so that watershed managers can provide reasonable recommendations for meeting water quality criteria in the river. Specifically, modeling scenarios were formulated to address the following: (1) baseline conditions, (2) a fertilizer reduction scenario, (3) streambank erosion reduction scenario, (4) upland erosion reduction scenario, (5) riparian buffer scenario, and (6) a livestock density reduction scenario.

8.1 Baseline Scenario

The baseline scenario describes existing conditions in the watershed and has been described previously (**Section 7.0**). Simulated values from this scenario form the basis for which all other scenarios will be compared.

8.2 Fertilizer Reduction Scenario

Agricultural fertilizer management was identified as a potential methodology for reducing nutrient loads in the Big Hole River. It is a common perception among watershed managers that fertilizer application rates could be decreased without affecting crop yield. This is most likely true, and for all intents and purposes, has already occurred due to prohibitive costs of fertilizer and through conservation strategies such as the Candidate Conservation Agreement with Assurances (CCAA) program. Reported cutbacks in the watershed are estimated at a change in application rate of 90.9 kg (200 lbs) of 29-6-6 mix application (nitrogen, phosphorus, potassium) to 45.5-68.2 kg/acre (100-150 lbs/acre) of 29-0-0 (personal communication, Erik Kalsta/Big Hole River Watershed Committee). Since DEQ considers this a reasonable BMP, the fertilizer reduction scenario was designed to estimate this nutrient reduction. Results are shown in **Table 20**. In general, very little change was observed in the watershed nutrient yield. This is due to the fact that hay/pasture is only a minor land use in most watersheds, as well as that some believe a greater amount of land is fertilized than characterized as hay/pasture in the NLCD (e.g. thus underestimating the actual influence fertilizer reduction). No investigations were completed to confirm this assertion.

Table 20. Nutrient reductions for fertilizer reduction scenario in the Big Hole River watershed.

Watershed	TN Reduction (kg)	Watershed Reduction (%)	TP Reduction (kg)	Watershed Reduction (%)
Francis	7.4	0.4%	4.9	1.3%
Steel	39.8	0.8%	21.6	2.3%
Jerry	19.0	0.4%	16.1	1.8%
Camp	17.9	0.5%	10.4	1.3%
Divide	18.1	0.3%	11.7	1.0%
Grose	0.1	0.2%	0.1	0.7%
Lost	2.2	0.2%	1.5	0.5%
Soap	2.2	0.2%	1.5	0.5%
Wickiup	5.6	0.7%	3.2	2.2%

The nitrogen EMC was reduced by 25 percent or 68.2/90.9 to reflect the change in application rate.

Phosphorus was adjusted to that of natural conditions (e.g. grassland), which totaled a 60 percent reduction.

8.2 Stream Bank Erosion Scenario

Stream bank erosion was identified as a nutrient source in many of the TMDL watersheds, therefore, a scenario was developed to address achievable pollutant reductions via stabilization of eroding or trampled stream banks. Relative reductions in bank erosion (in percent) were taken directly from the sediment TMDL, and then were applied to the computed streambank erosion load in GWLF to estimate the net change in nutrient load. Based on results of this scenario, watershed loads can be reduced by approximately 1-18 percent for nitrogen and 1-30 percent for phosphorus (**Table 21**).

Table 21. Nutrient reductions for the bank erosion scenario.

Watershed	GWLF Bank Load (kg x 1000)	Assumed Reduction (%)	TN Reduction (kg)	Watershed Reduction (%)	TP Reduction (kg)	Watershed Reduction (%)
Francis	166.06	26%	64.8	3.3%	26.8	7.1%
Steel	434.22	48%	312.6	6.6%	129.2	14.0%
Jerry	224.97	26%	87.7	1.1%	36.3	2.6%
Camp	109.54	43%	70.7	2.2%	29.2	3.8%
Divide	433.73	7%	45.5	0.7%	18.8	1.6%
Grose	13.43	62%	12.5	18.4%	5.2	30.5%
Lost	60.58	32%	29.1	3.1%	12.0	5.0%
Soap	58.93	11%	9.7	0.9%	4.0	1.3%
Wickiup	23.54	12%	4.2	0.5%	1.8	1.2%

8.3 Upland Erosion Scenario

Upland erosion was also considered for its underlying effect on nitrogen and phosphorus loads in TMDL watersheds. A similar procedure to the bank erosion scenario was completed, whereby results of the sediment TMDL were applied directly to computed values in GWLF (e.g. through changes in the cover management factor). Estimated reductions are shown in **Table 22**. Again, phosphorus was the nutrient most strongly associated with reductions in sedimentation.

Table 22. Nutrient reductions for the upland erosion scenario.

Watershed	GWLF Upland Load (kg x 1000)	Assumed Reduction (%)	TN Reduction (kg)	Watershed Reduction (%)	TP Reduction (kg)	Watershed Reduction (%)
Francis	108.07	14%	40.5	2.1%	16.7	4.4%
Steel	191.40	15%	69.5	1.5%	28.7	3.1%
Jerry	568.77	17%	144.7	1.8%	59.8	4.3%
Camp	631.70	20%	249.4	7.6%	103.1	13.3%
Divide	394.54	17%	164.9	2.6%	68.2	5.9%
Grose	12.69	19%	6.2	9.1%	2.6	15.1%
Lost	207.61	20%	89.4	9.5%	36.9	15.5%
Soap	335.45	21%	146.1	14.1%	60.4	19.7%
Wickiup	63.63	19%	27.2	3.5%	11.2	7.8%

8.4 Riparian Filter Strip Scenario

Riparian filter strips have been shown to be effective in removing phosphorus and nitrogen from surface water runoff and groundwater (Wegner, 1999; Peterjohn and Correll, 1985; Evans et al., 2001). In the case of the Big Hole River, it is believed riparian enhancement could have some utility in reducing nutrient loads in impaired watersheds. Filtering/uptake capacity is dependent on the condition of the riparian filter strip and associated width. Evans et al. (2001) provides filtering efficiencies for use in GWLF (**Table 23**).

Table 23. Assumed filtering efficiency of fully-functioning 10-m (30-ft) riparian buffer strip.

Phosphorus	Nitrogen	Sediment
54%	52%	58%

GWLF user's manual (Evans et al., 2001.)

Because certain locations in the watershed may already contain a functional buffer, DEQ derived four general conditions to provide an estimate of the current filtering capacity potential. These include non-functioning, partially-functioning, nearly-functioning, and functioning buffer strips as described below (determined from air photo assessment and greenline monitoring as):

1. Non-functioning – areas with severely degraded riparian zones having a very high proportion of bare banks, high lateral erosion rates, higher bare ground rates, and largely devoid of woody vegetation.

2. Partially-functioning – areas that have patchy riparian zones and could use more grazing management or setbacks from active hay production operations.
3. Nearly-functioning – areas that are in fair condition overall but have patchy areas that could use grazing BMPs.
4. Fully-functioning – well vegetated area with minimal impact and functioning as desired.

Using this information, the following assumptions regarding reduction attainability were made for each of the TMDL watersheds in the scenario:

- Francis Creek: 50 percent reduction potential for grassland, shrub, hay; 15 percent for forest
- Steel Creek: 50 percent reduction potential for grassland, shrub, hay
- Jerry Creek: 25 percent reduction potential in all areas
- Camp Creek: 25 percent reduction potential for hay; 15 percent for grassland, shrub, and forest
- Divide Creek: 15 percent reduction potential for grassland, shrub, hay
- Grose Creek: 25 percent reduction potential for hay; 15 percent for grassland, shrub, and forest
- Lost Creek: 25 percent reduction potential for hay; 15 percent for grassland, shrub, and forest
- Soap Creek: 25 percent reduction potential for hay; 15 percent for grassland, shrub, and forest
- Wickiup Creek: 15 percent reduction potential in all areas

The cumulative estimated effect of riparian filer strips is shown in **Table 24**.

Table 24. Nutrient reductions for the riparian filter strip scenario.

Watershed	TN Reduction	Watershed Reduction (%)	TP Reduction	Watershed Reduction (%)
Francis	468.4	23.9%	78.4	20.7%
Steel	851.7	18.1%	148.3	16.1%
Jerry	1849.4	23.4%	294.5	21.0%
Camp	437.3	13.4%	88.5	11.5%
Divide	308.9	4.9%	54.5	4.7%
Grose	6.7	9.9%	0.9	5.3%
Lost	116.8	12.4%	24.9	10.4%
Soap	123.6	11.9%	31.3	10.2%
Wickiup	106.3	13.7%	17.2	12.0%

Net filtering efficiency includes filtering of non-recoverable animal manure

8.5 Animal Stocking Density Scenario

Since animals are an anthropogenic source in many of the TMDL watersheds, a scenario was developed to assess relative stocking densities in the watershed (e.g. whether reductions in livestock should be recommended by DEQ). Forage biomass was used as the primary indicator of approximate maximum stocking rates, and recommended values from Dryland Pastures in Montana and Wyoming Species and Cultivars, Seeding Techniques and Grazing Management (MSU, 2003) were used as a general guideline for this estimate (**Table 25**). With conservative assumptions, such as a precipitation zone of 10-14 inches, and crested wheatgrass as the primary grassland forage, 0.61 hectares (1.5 acres) are required per animal unit per month (AUM). Assuming a six-month grazing period from May-October, 3.6 ha (9.0) acres would be required per animal unit (AU). Thus, the overall calculated carrying capacity of the study area upstream of Melrose is approximately 70,430 AU (using grassland as a surrogate for grazing area). When compared with the National Agricultural Statistics Service (NASS), current stocking density is 39,669 AU, which indicates that no reductions are necessary (**Table 26**). It should be noted, this is an estimate only (not considering available winter feed), and does not constitute a recommendation for increased livestock production in the watershed. Stocking density calculations are shown in **Appendix A4**.

Table 25. Stocking rate guidelines for dryland pastures and crop aftermath (MSU, 2003).

Pasture	Precipitation Zone (inches)	AUM Per Acre	Acre Per AUM
Crested wheatgrass	10–14	0.67	1.5
	15–18	1.00	1.0
Russian wildrye	10–14	0.50	2.0
	15–18	1.00	1.0
Pubescent wheatgrass	13–14	0.75	1.3
	15–18	1.25	0.8
Intermediate wheatgrass	14–18	1.50	0.7
Meadow bromegrass	16–18	1.50	0.7
Timothy	16–18	1.25	0.8
Orchardgrass	16–18	1.50	0.7
Grain aftermath	10-14 15-18	0.20 0.30	5.0 3.3
Hay aftermath	10-14 15-18	0.40 0.50	2.5 2.0

AUM = 1,000 lb cow/calf pair

Table 26. Nutrient reductions for the livestock density scenario.

Watershed	TN Reduction	Watershed Reduction (%)	TP Reduction	Watershed Reduction (%)
Francis	0.0	0.0%	0.0	0.0%
Steel	0.0	0.0%	0.0	0.0%
Jerry	0.0	0.0%	0.0	0.0%
Camp	0.0	0.0%	0.0	0.0%
Divide	0.0	0.0%	0.0	0.0%
Grose	0.0	0.0%	0.0	0.0%
Lost	0.0	0.0%	0.0	0.0%
Soap	0.0	0.0%	0.0	0.0%
Wickiup	0.0	0.0%	0.0	0.0%

SECTION 9.0 TMDL SCENARIO

A final scenario was formulated to assess the integrated effects of previous scenarios, e.g. effectively all reasonable soil and water conservation practices as outlined in ARM 17.30.602. Results were then compared to proposed interim nutrient criteria as outlined in **Section 1.2**. A summary of individual scenario results, combined nutrient reductions, and associated reduction percentages for each TMDL watershed is shown in **Table 27**, **Table 28**, and **Figure 21**. Individual results are detailed in **Figures 23-31** and **Tables 31-56**.

Table 27. Nitrogen reduction summary table.

Watershed	Fertilizer Scenario (kg)	Stream-bank Scenario	Upland Scenario (kg)	Filter Strip Scenario (kg)	Animal Scenario (kg)	Overall Reduction (kg)	Total Load (kg)	% Red.
Francis Cr	7.4	64.8	40.5	468.4	0.0	581.1	1,962.1	30%
Steel Cr	39.8	312.6	69.5	851.7	0.0	1,273.7	4,713.9	27%
Jerry Cr	19.0	87.7	144.7	1,849.4	0.0	2,100.9	7,920.0	27%
Camp Cr	17.9	70.7	249.4	437.3	0.0	775.2	3,265.5	24%
Divide Cr	18.1	45.5	164.9	308.9	0.0	537.4	6,306.9	9%
Grose Cr	0.1	12.5	6.2	6.7	0.0	25.6	67.9	38%
Lost Cr	2.2	29.1	89.4	116.8	0.0	237.5	939.4	25%
Soap Cr	2.2	9.7	146.1	123.6	0.0	281.6	1,037.0	27%
Wickiup Cr	5.6	4.2	27.2	106.3	0.0	143.3	776.9	18%

Table 28. Phosphorus reduction summary table

Watershed	Fertilizer Scenario (kg)	Stream-bank Scenario	Upland Scenario (kg)	Filter Strip Scenario (kg)	Animal Scenario (kg)	Overall Reduction (kg)	Total Load (kg)	% Red.
Francis Cr	4.9	26.8	16.7	78.4	0.0	126.8	379.3	33%
Steel Cr	21.6	129.2	28.7	148.3	0.0	327.9	922.1	36%
Jerry Cr	16.1	36.3	59.8	294.5	0.0	406.8	1,401.7	29%
Camp Cr	10.4	29.2	103.1	88.5	0.0	231.2	772.1	30%
Divide Cr	11.7	18.8	68.2	54.5	0.0	153.2	1,161.4	13%
Grose Cr	0.1	5.2	2.6	0.9	0.0	8.7	16.9	52%
Lost Cr	1.5	12.0	36.9	24.9	0.0	75.3	238.5	32%
Soap Cr	1.5	4.0	60.4	31.3	0.0	97.2	307.2	32%
Wickiup Cr	3.2	1.8	11.2	17.2	0.0	33.4	143.6	23%

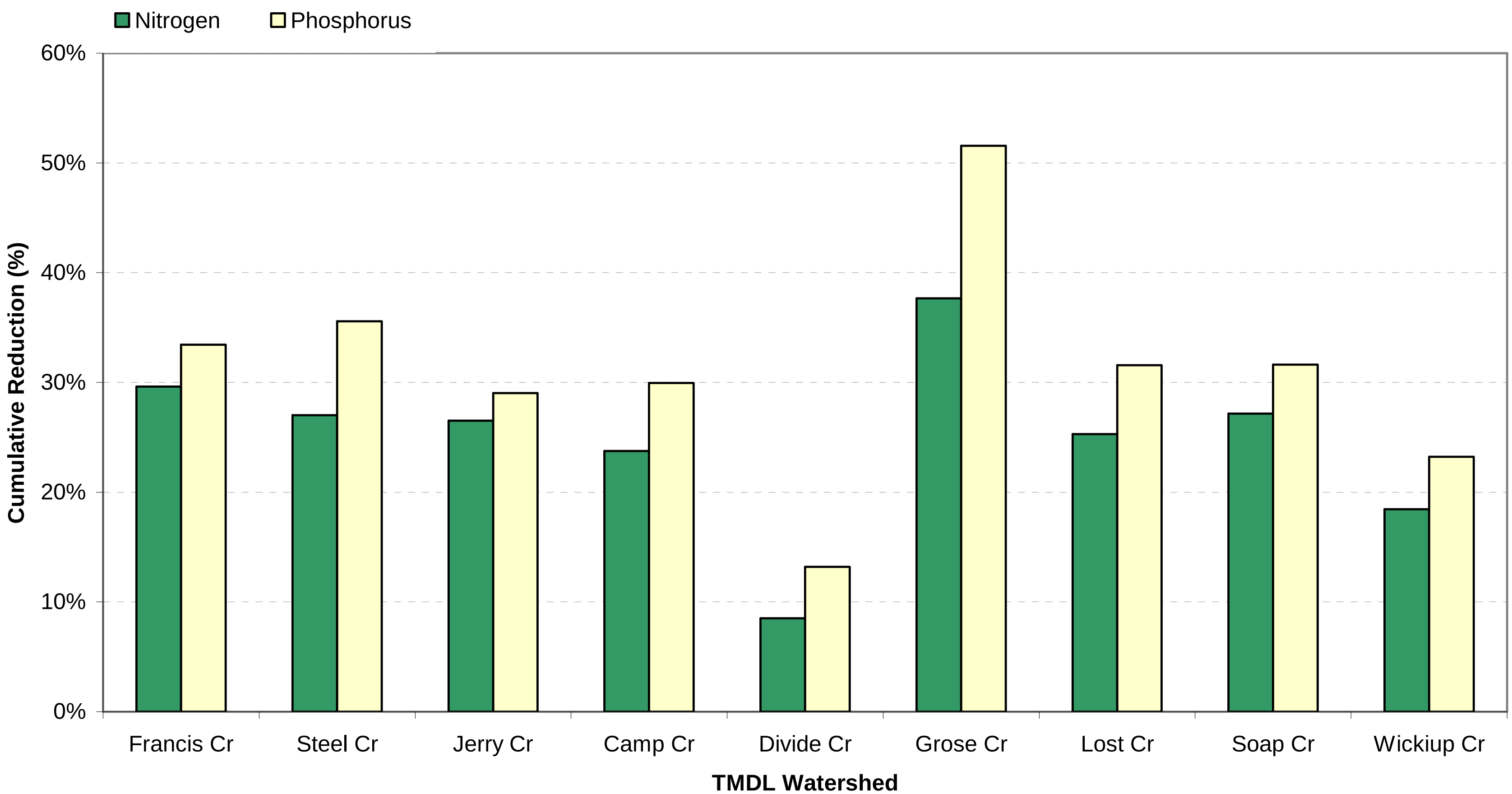


Figure 21. Summary of estimated nitrogen and phosphorus reductions in TMDL watersheds from implementation of all reasonable land, soil and water conservation practices (ARM 17.30.602).

9.1 Francis Creek

Estimated monthly streamflow, existing nutrient loads, interim criteria, BMP implementation loads, recommended restoration approaches, and proposed source allocations for Francis Creek are shown in **Figure 22**, **Table 29**, **Table 30**, and **Table 31**.

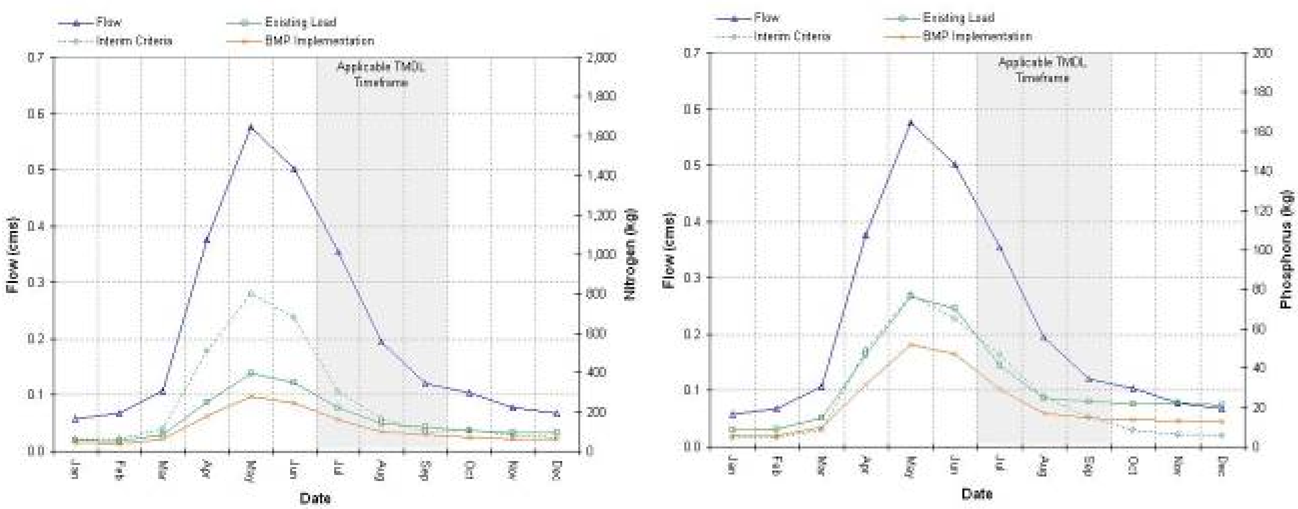


Figure 22. Estimated existing and proposed monthly loads of nitrogen and phosphorus in Francis Creek.

Table 29. Monthly tabular data of estimated monthly streamflow and pollutant loads for Francis Creek.

Month	Streamflow (cms)	Existing Condition Nitrogen Load (kg)	Nitrogen Criteria Load (kg)	BMP Nitrogen Load (kg)	Existing Condition Phosphorus Load (kg)	Phosphorus Criteria Load (kg)	BMP Phosphorus Load (kg)
Jan	0.06	57.2	61.0	41.2	8.4	4.7	5.7
Feb	0.07	52.2	63.5	37.1	8.7	4.9	5.9
Mar	0.11	84.8	111.7	60.5	14.9	8.6	10.0
Apr	0.38	248.0	507.9	177.9	46.5	48.8	31.8
May	0.58	394.0	802.5	280.6	76.6	77.2	52.1
Jun	0.50	350.4	677.2	246.1	70.1	65.1	47.0
Jul	0.35	220.9	304.2	158.7	41.6	46.6	29.1
Aug	0.19	140.6	166.7	100.8	24.5	25.5	16.9
Sep	0.12	122.4	100.0	84.5	23.0	15.3	14.7
Oct	0.10	103.3	109.2	70.1	21.7	8.4	13.5
Nov	0.08	96.3	78.7	63.2	22.0	6.1	13.2
Dec	0.07	92.0	71.1	60.2	21.1	5.5	12.6

Table 30. Nitrogen sources and loads, recommended restoration approaches, and proposed source allocations for Francis Creek.

Source Area	*Associated Human Activities*	*Existing Tot. N (kg)*	*Source Area Restoration Approach (reduction in kg)*	*Source Area Allocated Tot. N (kg)*	*Pollutant Filtering via Riparian Vegetation Improvement (reduction in kg)*	*Total Allocated Load From Source (kg)*
Hay/Past	Grazing Hay Production Fertilizer	99.3	Fertilizer/Grazing Management 7.6	91.7	50% 45.8	45.8
Shrub and Grassland	Grazing	578.2	Upland grazing management 40.3	537.9	50% 268.9	268.9
Forest	Grazing Timber Harvest	1024.5	NA	1024.5	15% 153.7	870.8
Developed	Urban	11.1	NA	11.1	0	11.1
Stream Banks	Grazing Hay encroachment	249.1	Riparian Vegetation restoration and grazing management 64.8	184.3	NA	184.3
Point Sources	Waste Load Allocation	0.0	NA	0.0	0	0.0
Future Sources	All	0.0	NA	0.0	0	0.0
Total Estimated Annual Load		1962.1	112.7	1849.4	468.4	1381.0
Estimated overall % reduction			6%		25%	30%

Table 31. Phosphorus sources and loads, recommended restoration approaches, and proposed source allocations for Francis Creek.

Source Area	*Associated Human Activities*	*Existing Tot. P (lbs)*	*Source Area Restoration Approach (reduction in lbs)*	*Source Area Allocated Tot. P (lbs)*	*Pollutant Filtering via Riparian Vegetation Improvement (reduction in lbs)*	*Total Allocated Load From Source (lbs)*
Hay/Past	Grazing Hay Production Fertilizer	8.4	Fertilizer/Grazing Management 5.0	3.5	50% 1.7	1.7
Shrub and Grassland	Grazing	129.1	Upland grazing management 16.7	112.4	50% 56.2	56.2
Forest	Grazing Timber Harvest	136.5	NA	136.5	15% 20.5	116.0
Developed	Urban	2.3	NA	2.3	0	2.3
Stream Banks	Grazing Hay encroachment	103.0	Riparian Vegetation restoration and grazing management 26.8	76.2	NA	76.2
Point Sources	Waste Load Allocation	0.0	NA	0.0	0	0.0
Future Sources	All	0.0	NA	0.0	0	0.0
Total Estimated Annual Load		379.3	48.4	330.8	78.4	252.4
Estimated overall % reduction			13%		24%	33%

9.2 Steel Creek

Estimated monthly streamflow, existing nutrient loads, interim criteria, BMP implementation loads, recommended restoration approaches, and proposed source allocations for Steel Creek are shown in **Figure 23**, **Table 32**, **Table 33**, and **Table 34**.

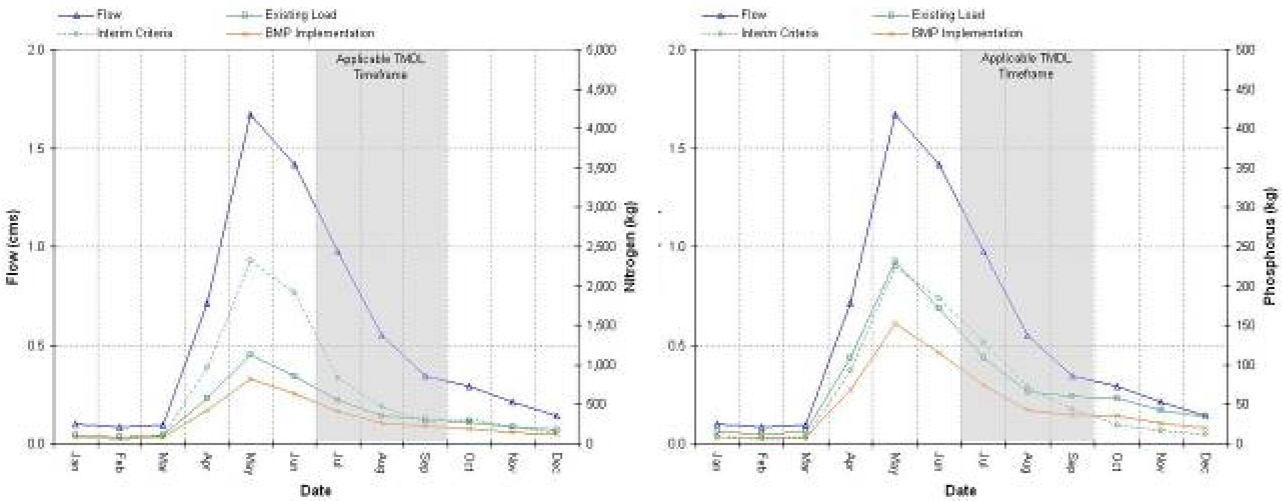


Figure 23. Estimated monthly loads of nitrogen and phosphorus in Steel Creek; including existing conditions, interim criteria, and BMP implementation results.

Table 32. Monthly tabular data of estimated monthly streamflow and pollutant loads for Steel Creek.

Month	Streamflow (cms)	Existing Condition Nitrogen Load	Nitrogen Criteria Load (kg)	BMP Nitrogen Load (kg)	Existing Condition Phosphorus Load (kg)	Phosphorus Criteria Load (kg)	BMP Phosphorus Load (kg)
Jan	0.10	111.1	103.7	82.0	14.9	8.0	8.8
Feb	0.08	84.7	79.3	61.4	12.2	6.1	7.0
Mar	0.09	104.5	97.6	76.7	14.7	7.5	8.6
Apr	0.71	574.7	959.5	419.8	109.1	92.3	68.1
May	1.67	1125.3	2325.7	827.2	231.5	223.6	152.7
Jun	1.42	854.2	1911.0	630.7	171.2	183.7	114.9
Jul	0.98	548.4	835.7	405.9	108.9	128.0	73.4
Aug	0.55	354.3	470.4	259.9	65.4	72.0	42.3
Sep	0.34	310.8	285.2	222.7	59.7	43.7	36.9
Oct	0.29	266.9	304.9	187.2	57.9	23.5	35.3
Nov	0.21	206.1	213.5	145.0	42.3	16.4	25.6
Dec	0.14	172.9	146.4	121.9	34.1	11.3	20.5

Table 33. Nitrogen sources and loads, recommended restoration approaches, and proposed source allocations for Steel Creek.

Source Area	Associated Human Activities	Existing Tot. N (kg)	Source Area Restoration Approach (reduction in kg)	Source Area Allocated Tot. N (kg)	Pollutant Filtering via Riparian Vegetation Improvement (reduction in kg)	Total Allocated Load From Source (kg)
Hay/Past	Grazing Hay Production Fertilizer	338.7	Fertilizer/Grazing Management 40.8	297.9	50% 149.0	149.0
Shrub and Grassland	Grazing	1474.0	Upland grazing management 68.6	1405.4	50% 702.7	702.7
Forest	Grazing Timber Harvest	2192.4	NA	2192.4	0% 0.0	2192.4
Developed	Urban	57.5	NA	57.5	0	57.5
Stream Banks	Grazing Hay encroachment	651.3	Riparian Vegetation restoration and grazing management 312.6	338.7	NA	338.7
Point Sources	Waste Load Allocation	0.0	NA	0.0	0	0.0
Future Sources	All	0.0	NA	0.0	0	0.0
Total Estimated Annual Load		4713.9	422.0	4291.9	851.7	3440.3
Estimated overall % reduction			9%		20%	27%

Table 34. Phosphorus sources and loads, recommended restoration approaches, and proposed source allocations for Steel Creek.

Source Area	*Associated Human Activities*	*Existing Tot. P (lbs)*	*Source Area Restoration Approach (reduction in lbs)*	*Source Area Allocated Tot. P (lbs)*	*Pollutant Filtering via Riparian Vegetation Improvement (reduction in lbs)*	*Total Allocated Load From Source (lbs)*
Hay/Past	Grazing Hay Production Fertilizer	37.2	Fertilizer/Grazing Management 22.0	15.2	50% 7.6	7.6
Shrub and Grassland	Grazing	309.8	Upland grazing management 28.4	281.5	50% 140.7	140.7
Forest	Grazing Timber Harvest	296.3	NA	296.3	0% 0.0	296.3
Developed	Urban	9.5	NA	9.5	0	9.5
Stream Banks	Grazing Hay encroachment	269.2	Riparian Vegetation restoration and grazing management 129.2	140.0	NA	140.0
Point Sources	Waste Load Allocation	0.0	NA	0.0	0	0.0
Future Sources	All	0.0	NA	0.0	0	0.0
Total Estimated Annual Load		922.1	179.6	742.5	148.3	594.1
Estimated overall % reduction			19%		20%	36%

9.3 Jerry Creek

Estimated monthly streamflow, existing nutrient loads, interim criteria, BMP implementation loads, recommended restoration approaches, and proposed source allocations for Jerry Creek are shown in **Figure 24**, **Table 35**, **Table 36**, and **Table 37**.

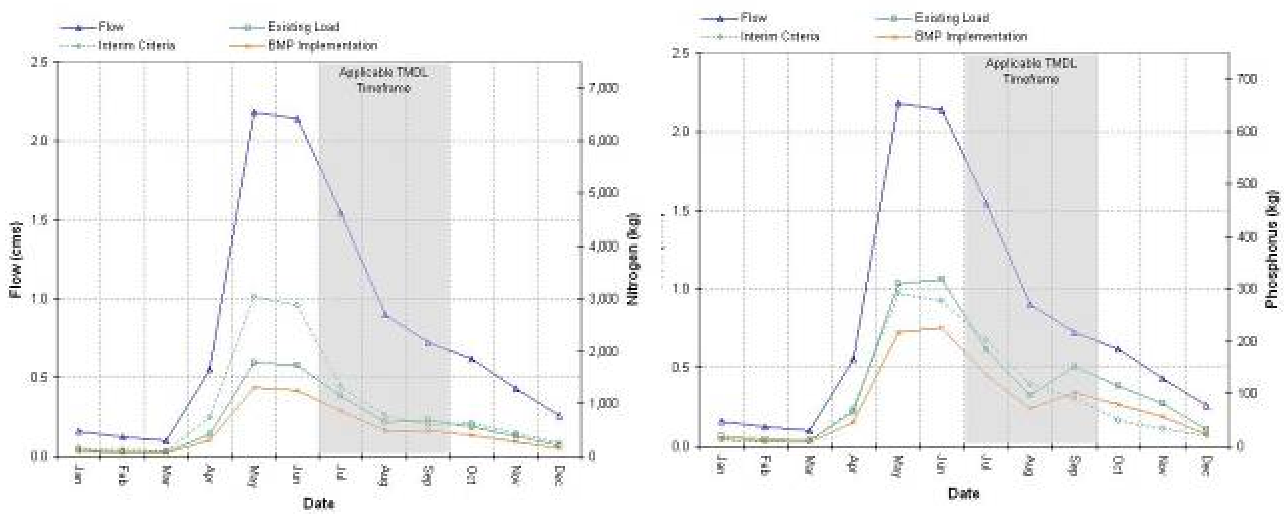


Figure 24. Estimated monthly loads of nitrogen and phosphorus in Jerry Creek; including existing conditions, interim criteria, and BMP implementation results.

Table 35. Monthly tabular data of estimated monthly streamflow and pollutant loads for Jerry Creek.

Month	Streamflow (cms)	Existing Condition Nitrogen Load (kg)	Nitrogen Criteria Load (kg)	BMP Nitrogen Load (kg)	Existing Condition Phosphorus Load (kg)	Phosphorus Criteria Load (kg)	BMP Phosphorus Load (kg)
Jan	0.16	129.3	166.8	96.2	19.0	12.8	13.9
Feb	0.12	91.8	115.8	67.9	13.9	8.9	10.0
Mar	0.10	87.2	106.5	64.6	12.9	8.2	9.3
Apr	0.55	426.2	747.3	317.1	66.1	71.9	46.8
May	2.18	1782.2	3038.6	1313.6	309.5	292.2	218.1
Jun	2.14	1726.6	2884.2	1264.5	318.5	277.3	226.6
Jul	1.54	1152.9	1322.6	861.7	184.2	202.5	136.3
Aug	0.90	658.8	775.3	496.1	97.3	118.7	73.2
Sep	0.72	697.1	600.5	494.4	151.3	92.0	102.1
Oct	0.62	562.6	643.9	404.2	114.6	49.5	78.9
Nov	0.43	397.3	435.4	284.3	82.1	33.5	56.3
Dec	0.26	208.0	273.3	154.7	32.3	21.0	23.5

Table 36. Nitrogen sources and loads, recommended restoration approaches, and proposed source allocations for Jerry Creek.

Source Area	Associated Human Activities	Existing Tot. N (kg)	Source Area Restoration Approach (reduction in kg)	Source Area Allocated Tot. N (kg)	Pollutant Filtering via Riparian Vegetation Improvement (reduction in kg)	Total Allocated Load From Source (kg)
Hay/Past	Grazing Hay Production Fertilizer	114.5	Fertilizer/Grazing Management 19.0	95.5	25% 23.9	71.6
Shrub and Grassland	Grazing	1370.6	Upland grazing management 144.7	1225.9	25% 306.5	919.4
Forest	Grazing Timber Harvest	6076.3	NA	6076.3	25% 1519.1	4557.3
Developed	Urban	21.2	NA	21.2	0	21.2
Stream Banks	Grazing Hay encroachment	337.5	Riparian Vegetation restoration and grazing management 87.7	249.7	NA	249.7
Point Sources	Waste Load Allocation	0.0	NA	0.0	0	0.0
Future Sources	All	0.0	NA	0.0	0	0.0
Total Estimated Annual Load		7920.0	251.4	7668.6	1849.4	5819.2
Estimated overall % reduction			3%		24%	27%

Table 37. Phosphorus sources and loads, recommended restoration approaches, and proposed source allocations for Jerry Creek.

Source Area	*Associated Human Activities*	*Existing Tot. P (lbs)*	*Source Area Restoration Approach (reduction in lbs)*	*Source Area Allocated Tot. P (lbs)*	*Pollutant Filtering via Riparian Vegetation Improvement (reduction in lbs)*	*Total Allocated Load From Source (lbs)*
Hay/Past	Grazing Hay Production Fertilizer	27.0	Fertilizer/Grazing Management 16.2	10.8	25% 2.7	8.1
Shrub and Grassland	Grazing	457.0	Upland grazing management 59.8	397.1	25% 99.3	297.9
Forest	Grazing Timber Harvest	770.2	NA	770.2	25% 192.5	577.6
Developed	Urban	8.2	NA	8.2	0	8.2
Stream Banks	Grazing Hay encroachment	139.5	Riparian Vegetation restoration and grazing management 36.3	103.2	NA	103.2
Point Sources	Waste Load Allocation	0.0	NA	0.0	0	0.0
Future Sources	All	0.0	NA	0.0	0	0.0
Total Estimated Annual Load		1401.7	112.2	1289.5	294.5	995.0
Estimated overall % reduction			8%		23%	29%

9.4 Camp Creek

Estimated monthly streamflow, existing nutrient loads, interim criteria, BMP implementation loads, recommended restoration approaches, and proposed source allocations for Camp Creek are shown in **Figure 26**, **Table 38**, **Table 39, and Table 40**.

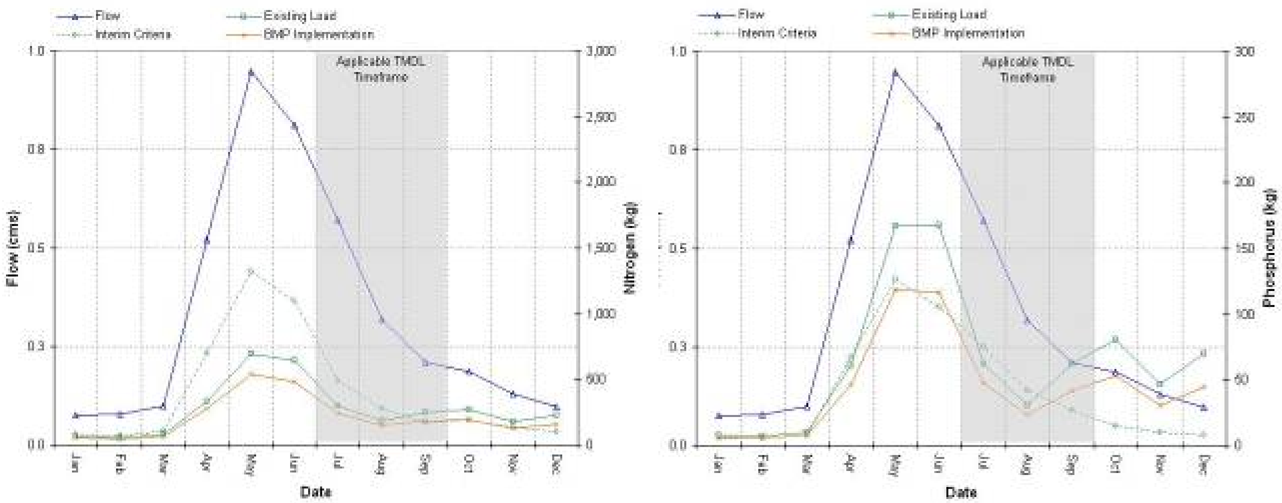


Figure 25. Estimated monthly loads of nitrogen and phosphorus in Camp Creek; including existing conditions, interim criteria, and BMP implementation results.

Table 38. Monthly tabular data of estimated monthly streamflow and pollutant load for Camp Creek.

Month	Streamflow (cms)	Existing Condition Nitrogen Load (kg)	Nitrogen Criteria Load (kg)	BMP Nitrogen Load (kg)	Existing Condition Phosphorus Load (kg)	Phosphorus Criteria Load (kg)	BMP Phosphorus Load (kg)
Jan	0.08	67.0	79.6	55.7	7.6	6.1	5.8
Feb	0.08	54.4	72.7	44.8	7.1	5.6	5.3
Mar	0.10	75.2	103.9	61.9	10.3	8.0	7.7
Apr	0.52	335.2	701.7	274.3	60.6	67.5	45.8
May	0.95	694.5	1320.3	535.3	166.8	127.0	119.2
Jun	0.81	640.6	1094.1	478.0	167.9	105.2	116.7
Jul	0.57	298.9	488.6	240.7	62.0	74.8	47.4
Aug	0.32	180.8	272.7	148.7	30.1	41.8	23.4
Sep	0.21	248.3	173.3	182.1	62.4	26.5	41.6
Oct	0.19	269.6	193.9	188.5	80.8	14.9	52.8
Nov	0.13	175.0	131.6	125.9	46.6	10.1	30.6
Dec	0.10	225.8	100.4	154.2	69.9	7.7	44.7

Table 39. Nitrogen sources and loads, recommended restoration approaches, and proposed source allocations for Camp Creek.

Source Area	*Associated Human Activities*	*Existing Tot. N (kg)*	*Source Area Restoration Approach (reduction in kg)*	*Source Area Allocated Tot. N (kg)*	*Pollutant Filtering via Riparian Vegetation Improvement (reduction in kg)*	*Total Allocated Load From Source (kg)*
Hay/Past	Grazing Hay Production Fertilizer	186.9	Fertilizer/Grazing Management 18.2	168.8	25% 42.2	126.6
Shrub and Grassland	Grazing	1725.5	Upland grazing management 249.1	1476.4	15% 221.5	1254.9
Forest	Grazing Timber Harvest	1157.4	NA	1157.4	15% 173.6	983.8
Developed	Urban	31.3	NA	31.3	0	31.3
Stream Banks	Grazing Hay encroachment	164.3	Riparian Vegetation restoration and grazing management 70.7	93.7	NA	93.7
Point Sources	Waste Load Allocation	0.0	NA	0.0	0	0.0
Future Sources	All	0.0	NA	0.0	0	0.0
Total Estimated Annual Load		3265.5	337.9	2927.5	437.3	2490.3
Estimated overall % reduction			10%		15%	24%

Table 40. Phosphorus sources and loads, recommended restoration approaches, and proposed source allocations for Camp Creek.

Source Area	*Associated Human Activities*	*Existing Tot. P (lbs)*	*Source Area Restoration Approach (reduction in lbs)*	*Source Area Allocated Tot. P (lbs)*	*Pollutant Filtering via Riparian Vegetation Improvement (reduction in lbs)*	*Total Allocated Load From Source (lbs)*
Hay/Past	Grazing Hay Production Fertilizer	17.7	Fertilizer/Grazing Management 10.5	7.2	25% 1.8	5.4
Shrub and Grassland	Grazing	517.9	Upland grazing management 103.0	414.9	15% 62.2	352.7
Forest	Grazing Timber Harvest	163.3	NA	163.3	15% 24.5	138.8
Developed	Urban	5.4	NA	5.4	0	5.4
Stream Banks	Grazing Hay encroachment	67.9	Riparian Vegetation restoration and grazing management 29.2	38.7	NA	38.7
Point Sources	Waste Load Allocation	0.0	NA	0.0	0	0.0
Future Sources	All	0.0	NA	0.0	0	0.0
Total Estimated Annual Load		772.1	142.7	629.5	88.5	541.0
Estimated overall % reduction			18%		14%	30%

9.5 Divide Creek

Estimated monthly streamflow, existing nutrient loads, interim criteria, BMP implementation loads, recommended restoration approaches, and proposed source allocations for Divide Creek are shown in **Figure 26**, **Table 41**, **Table 42** and **Table 43**.

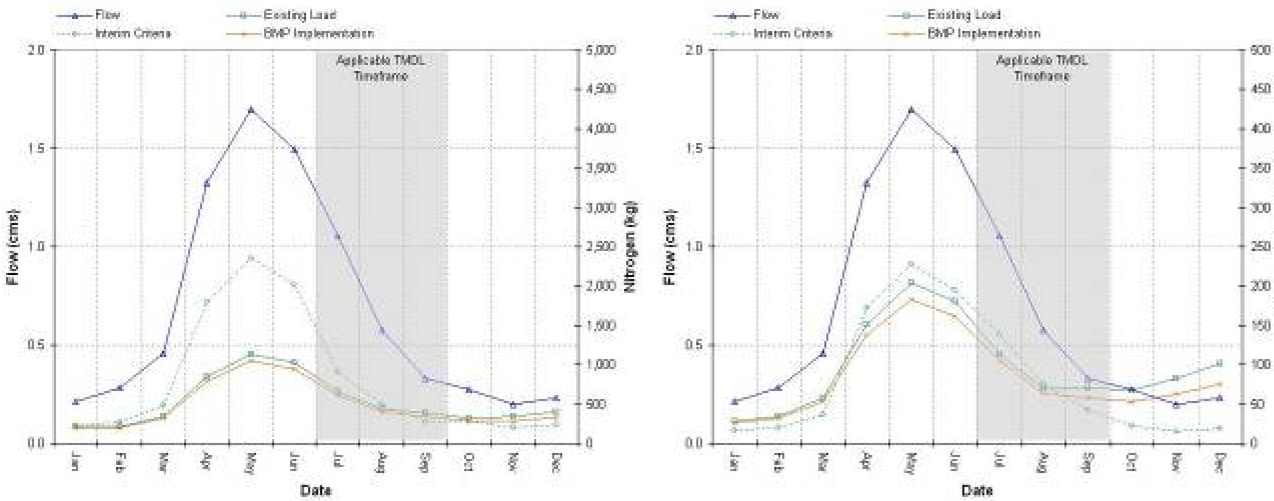


Figure 26. Estimated monthly loads of nitrogen and phosphorus in Divide Creek; including existing conditions, interim criteria, and BMP implementation results.

Table 41. Monthly tabular data of estimated monthly streamflow and pollutant load for Divide Creek.

Month	Streamflow (cms)	Existing Condition Nitrogen Load (kg)	Nitrogen Criteria Load (kg)	BMP Nitrogen Load (kg)	Existing Condition Phosphorus Load (kg)	Phosphorus Criteria Load (kg)	BMP Phosphorus Load (kg)
Jan	0.21	208.0	220.3	195.1	28.5	16.9	25.9
Feb	0.28	215.2	268.2	201.5	34.5	20.6	31.4
Mar	0.46	342.5	478.9	320.7	57.6	36.8	52.5
Apr	1.33	849.1	1788.0	794.5	151.3	171.9	137.5
May	1.70	1127.1	2362.8	1046.7	203.5	227.2	182.5
Jun	1.50	1020.8	2017.9	944.2	180.7	194.0	161.0
Jul	1.05	655.4	903.8	617.1	112.9	138.4	105.0
Aug	0.58	431.1	495.1	403.3	69.7	75.8	63.7
Sep	0.33	389.9	275.1	347.4	70.9	42.1	57.8
Oct	0.28	323.4	287.4	283.1	67.3	22.1	53.6
Nov	0.20	343.1	201.2	285.4	83.1	15.5	62.1
Dec	0.23	401.2	239.5	330.5	101.4	18.4	75.2

Table 42. Nitrogen sources and loads, recommended restoration approaches, and proposed source allocations for Divide Creek.

Source Area	Associated Human Activities	Existing Tot. N (kg)	Source Area Restoration Approach (reduction in kg)	Source Area Allocated Tot. N (kg)	Pollutant Filtering via Riparian Vegetation Improvement (reduction in kg)	Total Allocated Load From Source (kg)
Hay/Past	Grazing Hay Production Fertilizer	324.0	Fertilizer/Grazing Management 18.4	305.6	15% 45.8	259.8
Shrub and Grassland	Grazing	1918.1	Upland grazing management 164.6	1753.5	15% 263.0	1490.5
Forest	Grazing Timber Harvest	3283.6	NA	3283.6	0% 0.0	3283.6
Developed	Urban	130.6	NA	130.6	0	130.6
Stream Banks	Grazing Hay encroachment	650.6	Riparian Vegetation restoration and grazing management 45.5	605.1	NA	605.1
Point Sources	Waste Load Allocation	0.0	NA	0.0	0	0.0
Future Sources	All	0.0	NA	0.0	0	0.0
Total Estimated Annual Load		6306.9	228.5	6078.4	308.9	5769.5
Estimated overall % reduction			4%		5%	9%

Table 43. Phosphorus sources and loads, recommended restoration approaches, and proposed source allocations for Divide Creek.

Source Area	*Associated Human Activities*	*Existing Tot. P (lbs)*	*Source Area Restoration Approach (reduction in lbs)*	*Source Area Allocated Tot. P (lbs)*	*Pollutant Filtering via Riparian Vegetation Improvement (reduction in lbs)*	*Total Allocated Load From Source (lbs)*
Hay/Past	Grazing Hay Production Fertilizer	20.0	Fertilizer/Grazing Management 11.8	8.2	15% 1.2	7.0
Shrub and Grassland	Grazing	423.4	Upland grazing management 68.0	355.4	15% 53.3	302.1
Forest	Grazing Timber Harvest	430.7	NA	430.7	0% 0.0	430.7
Developed	Urban	18.3	NA	18.3	0	18.3
Stream Banks	Grazing Hay encroachment	268.9	Riparian Vegetation restoration and grazing management 18.8	250.1	NA	250.1
Point Sources	Waste Load Allocation	0.0	NA	0.0	0	0.0
Future Sources	All	0.0	NA	0.0	0	0.0
Total Estimated Annual Load		1161.4	98.7	1062.7	54.5	1008.2
Estimated overall % reduction			8%		5%	13%

9.6 Grose Creek

Estimated monthly streamflow, existing nutrient loads, interim criteria, BMP implementation loads, recommended restoration approaches, and proposed source allocations for Grose Creek are shown in **Figure 27**, **Table 44**, **Table 45** and **Table 46**.

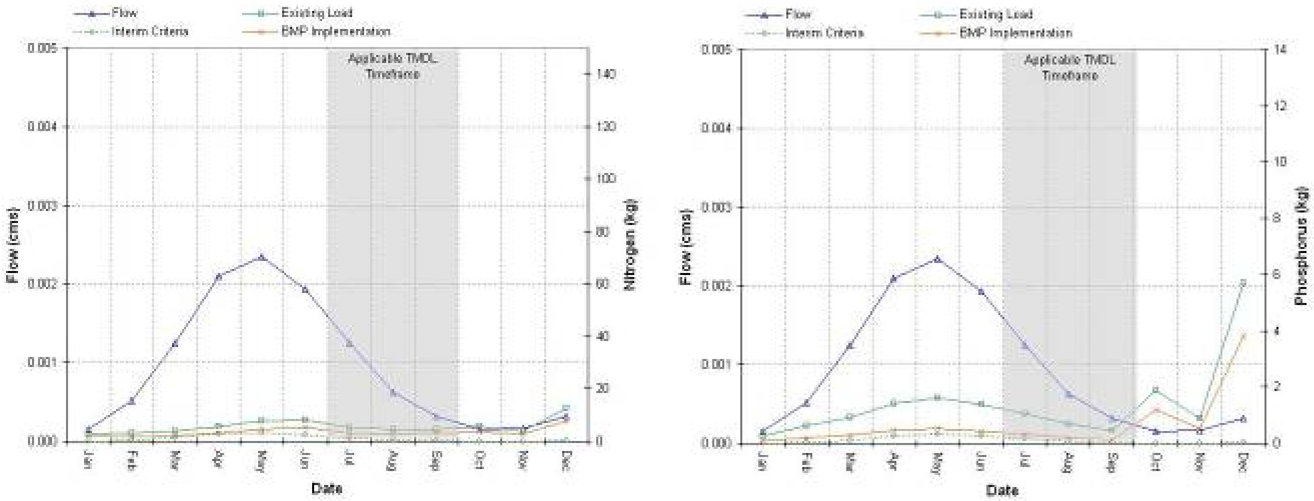


Figure 27. Estimated monthly loads of nitrogen and phosphorus in Grose Creek; including existing conditions, interim criteria, and BMP implementation results.

Table 44. Monthly tabular data of estimated monthly streamflow and pollutant load for Grose Creek.

Month	Streamflow (cms)	Existing Condition Nitrogen Load (kg)	Nitrogen Criteria Load (kg)	BMP Nitrogen Load (kg)	Existing Condition Phosphorus Load (kg)	Phosphorus Criteria Load (kg)	BMP Phosphorus Load (kg)
Jan	0.00	2.7	0.2	2.0	0.3	0.0	0.1
Feb	0.00	3.0	0.5	1.8	0.6	0.0	0.2
Mar	0.00	3.9	1.3	2.1	0.9	0.1	0.3
Apr	0.00	5.8	2.8	3.1	1.4	0.3	0.5
May	0.00	7.8	3.3	4.6	1.6	0.3	0.5
Jun	0.00	8.2	2.6	5.3	1.4	0.3	0.4
Jul	0.00	5.2	1.1	3.1	1.0	0.2	0.3
Aug	0.00	4.5	0.5	3.0	0.7	0.1	0.2
Sep	0.00	4.4	0.3	3.2	0.5	0.0	0.1
Oct	0.00	5.5	0.2	3.5	1.9	0.0	1.2
Nov	0.00	3.8	0.2	2.7	0.9	0.0	0.5
Dec	0.00	12.9	0.3	7.8	5.7	0.0	3.8

Table 45. Nitrogen sources and loads, recommended restoration approaches, and proposed source allocations for Grose Creek.

Source Area	Associated Human Activities	Existing Tot. N (kg)	Source Area Restoration Approach (reduction in kg)	Source Area Allocated Tot. N (kg)	Pollutant Filtering via Riparian Vegetation Improvement (reduction in kg)	Total Allocated Load From Source (kg)
Hay/Past	Grazing Hay Production Fertilizer	5.9	Fertilizer/Grazing Management 0.2	5.7	25% 1.4	4.3
Shrub and Grassland	Grazing	36.3	Upland grazing management 6.2	30.2	15% 4.5	25.7
Forest	Grazing Timber Harvest	5.3	NA	5.3	15% 0.8	4.5
Developed	Urban	0.2	NA	0.2	0	0.2
Stream Banks	Grazing Hay encroachment	20.1	Riparian Vegetation restoration and grazing management 12.5	7.7	NA	7.7
Point Sources	Waste Load Allocation	0.0	NA	0.0	0	0.0
Future Sources	All	0.0	NA	0.0	0	0.0
Total Estimated Annual Load		67.9	18.8	49.1	6.7	42.3
Estimated overall % reduction			28%		14%	38%

Table 46. Phosphorus sources and loads, recommended restoration approaches, and proposed source allocations for Grose Creek.

Source Area	Associated Human Activities	Existing Tot. P (lbs)	Source Area Restoration Approach (reduction in lbs)	Source Area Allocated Tot. P (lbs)	Pollutant Filtering via Riparian Vegetation Improvement (reduction in lbs)	Total Allocated Load From Source (lbs)
Hay/Past	Grazing Hay Production Fertilizer	0.2	Fertilizer/Grazing Management 0.1	0.1	25% 0.0	0.1
Shrub and Grassland	Grazing	8.3	Upland grazing management 2.5	5.8	15% 0.9	4.9
Forest	Grazing Timber Harvest	0.0	NA	0.0	15% 0.0	0.0
Developed	Urban	0.0	NA	0.0	0	0.0
Stream Banks	Grazing Hay encroachment	8.3	Riparian Vegetation restoration and grazing management 5.2	3.2	NA	3.2
Point Sources	Waste Load Allocation	0.0	NA	0.0	0	0.0
Future Sources	All	0.0	NA	0.0	0	0.0
Total Estimated Annual Load		16.9	7.8	9.1	0.9	8.2
Estimated overall % reduction			46%		10%	52%

9.7 Lost Creek

Estimated monthly streamflow, existing nutrient loads, interim criteria, BMP implementation loads, recommended restoration approaches, and proposed source allocations for Lost Creek are shown in **Figure 28**, **Table 47**, **Table 48**, and **Table 49**.

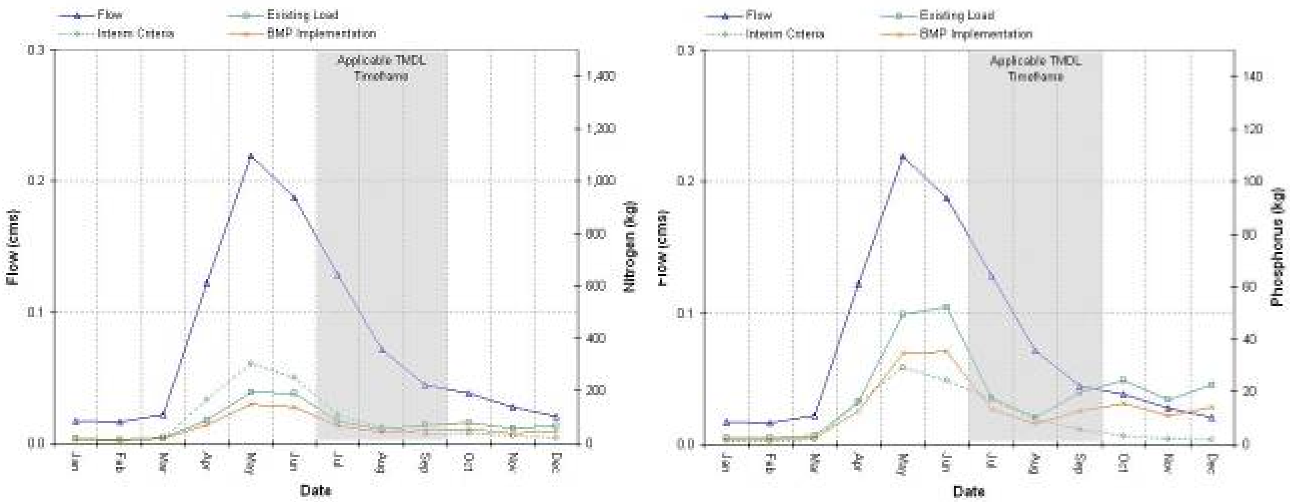


Figure 28. Estimated monthly loads of nitrogen and phosphorus in Lost Creek; including existing conditions, interim criteria, and BMP implementation results.

Table 47. Monthly tabular data of estimated monthly streamflow and pollutant load for Lost Creek.

Month	Streamflow (cms)	Existing Condition Nitrogen Load (kg)	Nitrogen Criteria Load (kg)	BMP Nitrogen Load (kg)	Existing Condition Phosphorus Load (kg)	Phosphorus Criteria Load (kg)	BMP Phosphorus Load (kg)
Jan	0.02	18.1	17.4	14.9	2.5	1.3	1.8
Feb	0.02	15.1	15.7	12.3	2.3	1.2	1.7
Mar	0.02	20.5	22.6	16.7	3.2	1.7	2.4
Apr	0.12	86.9	164.7	71.5	16.4	15.8	12.6
May	0.22	195.0	305.1	148.0	49.4	29.3	34.6
Jun	0.19	190.9	252.9	139.4	52.5	24.3	35.5
Jul	0.13	84.5	110.7	67.8	17.8	16.9	13.3
Aug	0.07	54.1	61.4	43.4	10.4	9.4	7.7
Sep	0.04	71.7	37.1	51.1	19.7	5.7	12.8
Oct	0.04	76.9	40.0	52.2	24.4	3.1	15.6
Nov	0.03	56.7	27.8	38.9	17.2	2.1	10.9
Dec	0.02	69.0	21.8	45.5	22.8	1.7	14.2

Table 48. Nitrogen sources and loads, recommended restoration approaches, and proposed source allocations for Lost Creek.

Source Area	*Associated Human Activities*	*Existing Tot. N (kg)*	*Source Area Restoration Approach (reduction in kg)*	*Source Area Allocated Tot. N (kg)*	*Pollutant Filtering via Riparian Vegetation Improvement (reduction in kg)*	*Total Allocated Load From Source (kg)*
Hay/Past	Grazing Hay Production Fertilizer	58.7	Fertilizer/Grazing Management 2.2	56.4	25% 14.1	42.3
Shrub and Grassland	Grazing	465.3	Upland grazing management 89.4	375.9	15% 56.4	319.5
Forest	Grazing Timber Harvest	309.0	NA	309.0	15% 46.3	262.6
Developed	Urban	15.6	NA	15.6	0	15.6
Stream Banks	Grazing Hay encroachment	90.9	Riparian Vegetation restoration and grazing management 29.1	61.8	NA	61.8
Point Sources	Waste Load Allocation	0.0	NA	0.0	0	0.0
Future Sources	All	0.0	NA	0.0	0	0.0
Total Estimated Annual Load		939.4	120.7	818.7	116.8	701.9
Estimated overall % reduction			13%		14%	25%

Table 49. Phosphorus sources and loads, recommended restoration approaches, and proposed source allocations for Lost Creek.

Source Area	Associated Human Activities	Existing Tot. P (lbs)	Source Area Restoration Approach (reduction in lbs)	Source Area Allocated Tot. P (lbs)	Pollutant Filtering via Riparian Vegetation Improvement (reduction in lbs)	Total Allocated Load From Source (lbs)
Hay/Past	Grazing Hay Production Fertilizer	12.6	Fertilizer/Grazing Management 1.5	11.1	25% 2.8	8.3
Shrub and Grassland	Grazing	149.1	Upland grazing management 36.9	112.2	15% 16.8	95.3
Forest	Grazing Timber Harvest	35.1	NA	35.1	15% 5.3	29.8
Developed	Urban	4.2	NA	4.2	0	4.2
Stream Banks	Grazing Hay encroachment	37.6	Riparian Vegetation restoration and grazing management 12.0	25.5	NA	25.5
Point Sources	Waste Load Allocation	0.0	NA	0.0	0	0.0
Future Sources	All	0.0	NA	0.0	0	0.0
Total Estimated Annual Load		238.5	50.5	188.1	24.9	163.2
Estimated overall % reduction			21%		13%	32%

9.8 Soap Creek

Estimated monthly streamflow, existing nutrient loads, interim criteria, BMP implementation loads, recommended restoration approaches, and proposed source allocations for Soap Creek are shown in **Figure 29**, **Table 50**, **Table 51**, and **Table 52**.

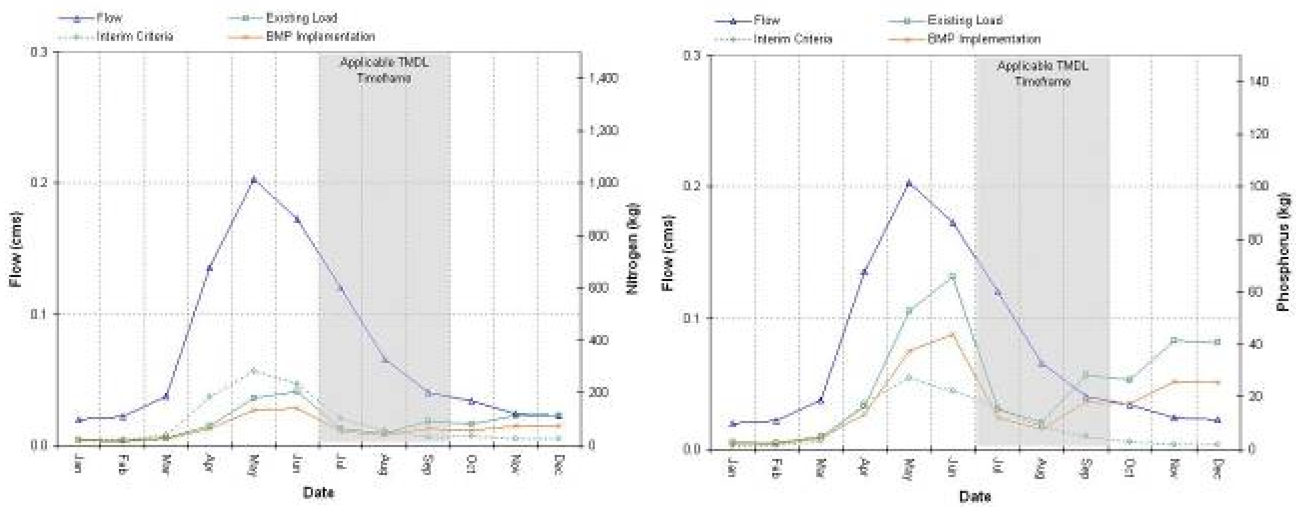


Figure 29. Estimated monthly loads of nitrogen and phosphorus in Soap Creek; including existing conditions, interim criteria, and BMP implementation results.

Table 50. Monthly tabular data of estimated monthly streamflow and pollutant load for Soap Creek.

Month	Streamflow (cms)	Existing Condition Nitrogen Load (kg)	Nitrogen Criteria Load (kg)	BMP Nitrogen Load (kg)	Existing Condition Phosphorus Load (kg)	Phosphorus Criteria Load (kg)	BMP Phosphorus Load (kg)
Jan	0.02	20.3	20.7	17.5	2.7	1.6	2.2
Feb	0.02	16.6	20.7	14.3	2.6	1.6	2.2
Mar	0.04	27.4	39.5	23.4	4.9	3.0	4.1
Apr	0.14	75.7	183.0	64.6	16.1	17.6	13.4
May	0.20	181.8	283.2	136.1	52.9	27.2	37.4
Jun	0.17	203.9	233.1	143.2	65.7	22.4	44.0
Jul	0.12	63.7	103.3	52.4	15.2	15.8	12.2
Aug	0.07	47.5	56.3	38.8	10.2	8.6	7.9
Sep	0.04	91.3	33.2	63.3	28.1	5.1	18.2
Oct	0.03	80.9	35.7	55.0	26.7	2.7	17.3
Nov	0.02	114.9	24.4	74.0	41.3	1.9	25.9
Dec	0.02	113.1	23.5	72.7	40.7	1.8	25.4

Table 51. Nitrogen sources and loads, recommended restoration approaches, and proposed source allocations for Soap Creek.

Source Area	Associated Human Activities	Existing Tot. N (kg)	Source Area Restoration Approach (reduction in kg)	Source Area Allocated Tot. N (kg)	Pollutant Filtering via Riparian Vegetation Improvement (reduction in kg)	Total Allocated Load From Source (kg)
Hay/Past	Grazing Hay Production Fertilizer	46.3	Fertilizer/Grazing Management 2.2	44.1	25% 11.0	33.1
Shrub and Grassland	Grazing	725.3	Upland grazing management 146.1	579.2	15% 86.9	492.3
Forest	Grazing Timber Harvest	171.2	NA	171.2	15% 25.7	145.5
Developed	Urban	5.8	NA	5.8	0	5.8
Stream Banks	Grazing Hay encroachment	88.4	Riparian Vegetation restoration and grazing management 9.7	78.7	NA	78.7
Point Sources	Waste Load Allocation	0.0	NA	0.0	0	0.0
Future Sources	All	0.0	NA	0.0	0	0.0
Total Estimated Annual Load		1037.0	158.0	878.9	123.6	755.4
Estimated overall % reduction			15%		14%	27%

Table 52. Phosphorus sources and loads, recommended restoration approaches, and proposed source allocations for Soap Creek.

Source Area	Associated Human Activities	Existing Tot. P (lbs)	Source Area Restoration Approach (reduction in lbs)	Source Area Allocated Tot. P (lbs)	Pollutant Filtering via Riparian Vegetation Improvement (reduction in lbs)	Total Allocated Load From Source (lbs)
Hay/Past	Grazing Hay Production Fertilizer	2.5	Fertilizer/Grazing Management 1.5	1.0	25% 0.3	0.8
Shrub and Grassland	Grazing	240.8	Upland grazing management 60.4	180.4	15% 27.1	153.3
Forest	Grazing Timber Harvest	26.4	NA	26.4	15% 3.9	22.4
Developed	Urban	1.0	NA	1.0	0	1.0
Stream Banks	Grazing Hay encroachment	36.5	Riparian Vegetation restoration and grazing management 4.0	32.5	NA	32.5
Point Sources	Waste Load Allocation	0.0	NA	0.0	0	0.0
Future Sources	All	0.0	NA	0.0	0	0.0
Total Estimated Annual Load		307.2	65.9	241.3	31.3	210.0
Estimated overall % reduction			21%		13%	32%

9.9 Wickiup Creek

Estimated monthly streamflow, existing nutrient loads, interim criteria, BMP implementation loads, recommended restoration approaches, and proposed source allocations for Wickiup Creek are shown in **Figure 30**, **Table 53**, **Table 54**, and **Table 55**.

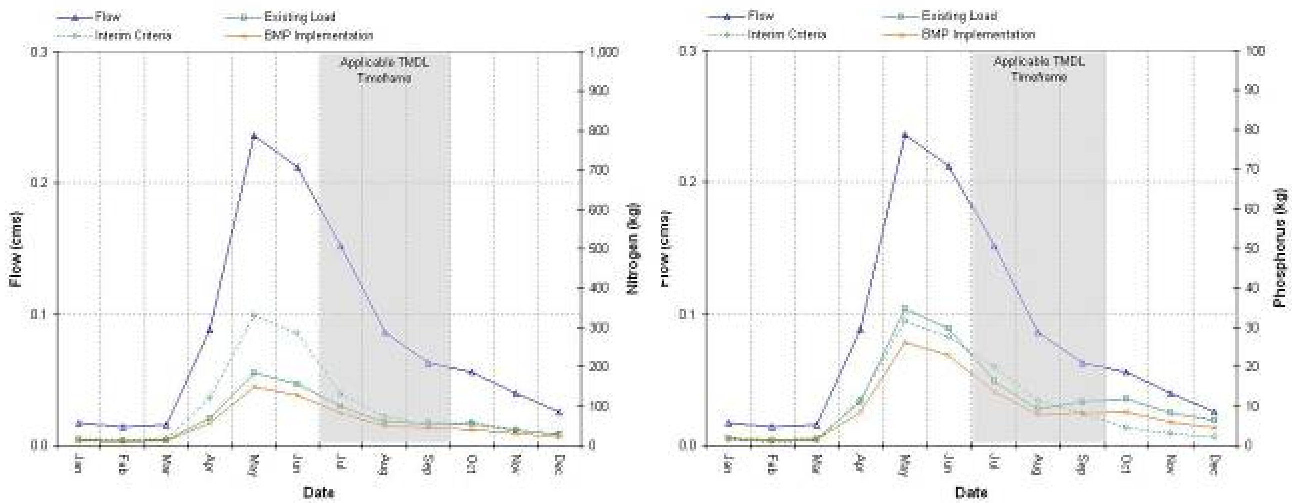


Figure 30. Estimated monthly loads of nitrogen and phosphorus in Wickiup Creek; including existing conditions, interim criteria, and BMP implementation results.

Table 53. Monthly tabular data of estimated monthly streamflow and pollutant load for Wickiup Creek.

Month	Streamflow (cms)	Existing Condition Nitrogen Load (kg)	Nitrogen Criteria Load (kg)	BMP Nitrogen Load (kg)	Existing Condition Phosphorus Load (kg)	Phosphorus Criteria Load (kg)	BMP Phosphorus Load (kg)
Jan	0.02	14.3	17.4	12.2	1.9	1.3	1.6
Feb	0.01	10.8	13.1	9.2	1.5	1.0	1.2
Mar	0.02	13.2	16.2	11.3	1.8	1.2	1.5
Apr	0.09	67.7	119.4	56.0	11.2	11.5	8.5
May	0.24	182.9	329.3	148.4	34.6	31.7	26.1
Jun	0.21	155.7	286.1	126.4	29.8	27.5	22.9
Jul	0.15	98.4	130.2	83.4	16.2	19.9	13.6
Aug	0.09	58.5	74.0	49.8	9.1	11.3	7.7
Sep	0.06	55.5	52.1	44.2	11.0	8.0	8.1
Oct	0.06	53.1	58.5	41.1	11.9	4.5	8.5
Nov	0.04	38.1	39.8	29.6	8.3	3.1	6.0
Dec	0.03	28.6	26.7	21.9	6.4	2.1	4.5

Table 54. Nitrogen sources and loads, recommended restoration approaches, and proposed source allocations for Wickiup Creek.

Source Area	*Associated Human Activities*	*Existing Tot. N (kg)*	*Source Area Restoration Approach (reduction in kg)*	*Source Area Allocated Tot. N (kg)*	*Pollutant Filtering via Riparian Vegetation Improvement (reduction in kg)*	*Total Allocated Load From Source (kg)*
Hay/Past	Grazing Hay Production Fertilizer	38.2	Fertilizer/Grazing Management 6.7	31.5	15% 4.7	26.8
Shrub and Grassland	Grazing	180.4	Upland grazing management 26.1	154.3	15% 23.1	131.2
Forest	Grazing Timber Harvest	523.0	NA	523.0	15% 78.4	444.5
Developed	Urban	0.0	NA	0.0	0	0.0
Stream Banks	Grazing Hay encroachment	35.3	Riparian Vegetation restoration and grazing management 4.2	31.1	NA	31.1
Point Sources	Waste Load Allocation	0.0	NA	0.0	0	0.0
Future Sources	All	0.0	NA	0.0	0	0.0
Total Estimated Annual Load		776.9	37.0	739.9	106.3	633.6
Estimated overall % reduction			5%		14%	18%

Table 55. Phosphorus sources and loads, recommended restoration approaches, and proposed source allocations for Wickiup Creek.

Source Area	*Associated Human Activities*	*Existing Tot. P (lbs)*	*Source Area Restoration Approach (reduction in lbs)*	*Source Area Allocated Tot. P (lbs)*	*Pollutant Filtering via Riparian Vegetation Improvement (reduction in lbs)*	*Total Allocated Load From Source (lbs)*
Hay/Past	Grazing Hay Production Fertilizer	6.6	Fertilizer/Grazing Management 3.6	3.0	15% 0.4	2.5
Shrub and Grassland	Grazing	50.4	Upland grazing management 10.8	39.6	15% 5.9	33.7
Forest	Grazing Timber Harvest	72.0	NA	72.0	15% 10.8	61.2
Developed	Urban	0.0	NA	0.0	0	0.0
Stream Banks	Grazing Hay encroachment	14.6	Riparian Vegetation restoration and grazing management 1.8	12.8	NA	12.8
Point Sources	Waste Load Allocation	0.0	NA	0.0	0	0.0
Future Sources	All	0.0	NA	0.0	0	0.0
Total Estimated Annual Load		143.6	16.2	127.4	17.2	110.2
Estimated overall % reduction			11%		13%	23%

9.10 TMDL Scenario Summary

Clearly, the combined benefit of BMP implementation is a general reduction of nutrient loading in the watersheds which closely approximates interim numeric criteria (in most cases). Thus it is believed that upland and streambank erosion mitigation, riparian buffer enhancement, and reductions in fertilizer application are appropriate BMP recommendations for the upcoming TMDL. Ultimately, it will be up to the discretion of the watershed managers on which options are recommended for future action.

SECTION 10.0
CONCLUSION

GWLF was used to simulate monthly nitrogen and phosphorous loads for the upcoming Big Hole River nutrient TMDL. Through modeling, it was found that forest, grassland, and shrub/scrub provide a large natural background load in most watersheds, and that a majority of the anthropogenic load is of agricultural origin. Sources identified during the project include non-recoverable animal manure, grazing, fertilization, and urban lands. Streambanks were also found to contribute a substantial nitrogen and phosphorus load. Following the source assessment, scenarios were formulated to assess the relative effectiveness of BMP treatments in each of the impaired watersheds. Riparian buffer strip enhancement was shown to be the most effective treatment and anthropogenic pollutant removal ranged from approximately 5-25 percent. When combined with other implementation practices such as streambank and upland erosion mitigation and fertilizer application decreases, reductions ranged from approximately 10-50 percent in each watershed. In most cases, the computed load following BMP implementation load very much approximated interim numeric nutrient criteria. As a result, the primary recommendation is establishment of functioning riparian buffers, followed by streambank and upland erosion reductions. Finally, a reminder should be made that the modeling was relatively low-certainty, and for all intensive purposes, computed loads and associated reductions used in the TMDL development are estimates only.

SECTION 11.0
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APPENDIX – A1 IRRIGATION CALCULATIONS

ET values for pasture/hay from Dillon AGRIMET site (1997-2006)

```
***************************************************************************
*     *   DAILY   *  *  *  *  *  *  *
*     * CROP WATER USE-(IN) * DAILY*   *   *   * 7 * 14 *
* CROP START* PENMAN ET - SEP * FORE *COVER* TERM* SUM * DAY* DAY *
*    DATE*---------------------* CAST * DATE* DATE* ET * USE* USE *
*     * 27  28  29  30 *   *   *   *   *  *   *
*-----------*---------------------*------*------------------*----------*-----
* PAST 420 * 0.00 0.00 0.00 0.00 * 0.00 * 530 * 920 * 18.4 * 0.0* 0.2  1997
* PAST 420 * 0.00 0.00 0.00 0.00 * 0.00 * 530 * 920 * 20.9 * 0.0* 0.2  1998
* PAST 420 * 0.00 0.00 0.00 0.00 * 0.00 * 530 * 920 * 20.9 * 0.0* 0.2  1999
* PAST 420 * 0.08 0.07 0.07 0.00 * 0.00 * 530 * 930 * 24.1 * 0.4* 1.0  2000
* PAST 420 * 0.09 0.06 0.07 0.00 * 0.00 * 530 * 930 * 24.6 * 0.5* 1.2  2001
* PAST 420 * 0.04 0.05 0.06 0.00 * 0.00 * 530 * 930 * 23.0 * 0.3* 0.9  2002
* PAST 420 * 0.08 0.06 0.08 0.00 * 0.00 * 530 * 930 * 25.6 * 0.5* 1.2  2003
* PAST 420 * 0.06 0.06 0.05 0.00 * 0.00 * 530 * 930 * 23.0 * 0.4* 0.7  2004
* PAST 420 * 0.08 0.06 0.08 0.00 * 0.00 * 530 * 930 * 22.9 * 0.4* 1.0  2005
* PAST 420 * 0.07 0.08 0.06 0.00 * 0.00 * 530 * 930 * 24.3 * 0.4* 0.8  2006
* PAST 420 * 0.08 0.05 0.02 0.00 * 0.00 * 530 * 930 * 25.2 * 0.4* 0.8  2007
*-----------*---------------------*------*------------------*----------*-----
                    AVG  22.7
```

Example irrigation calculation used in GWLF model of USGS Big Hole River nr Melrose, MT:

Irrigated area (pasture/hay) = 14,750 ha
Total watershed area = 636,522 ha
AGRIMET crop water use = 57.8 cm/yr (pasture) (22.7 inches)

$$= \frac{14{,}750ha}{636{,}522ha} \times 57.8cm/yr$$

Crop water use requirement = 1.4 cm/yr
Distribution losses = 25%

Net diversion value = 1.7 cm/yr (distribute over summer months)

APPENDIX – A2 LIVESTOCK CALCULATIONS

Livestock calculations used in GWLF modeling are detailed below.

Available Data:

National Agricultural Statistics Service data from 1998-2007 (NASS, 2008)

106,900 cows and calves
12,600 ewes and lambs
750 horses (estimated)

Convert to AUM (NRCS, 2003)
Assume: cow/calf pair = 1 AUM
ewe/lamb = 0.3 AUM
horse = 1.25 AUM

Livestock estimate for grazing season (May-October; 6 months)
53,450 pair cattle x 1 AUM x 6 = 320,700 AUM
6,300 pair sheep x 0.3 AUM x 6 = 11,340 AUM
750 horses x 6 = 5,625 AUM
= 337,665 AUM

Carrying capacity estimate

221,830 ha of grassland in watershed
0.61 ha (1.5 acres) per AUM

= 363,656 AUM

Stocking rate less than carrying capacity 

APPENDIX – A3 NON-RECOVERABLE ANIMAL MANURE CALCULATIONS

Table A3-1: 1950 CENSUS OF AGRICULTURE (USDA, 1952)						
MONTANA COUNTY DATA INVENTORY						
County	**Cattle**	**Hogs**	**Sheep**	**Horses**	**Poultry**	
Beaverhead	95,819	2,813	101,047	6,745	15,384	
Deer Lodge	5,611	1,015	9,668	560	8,402	
Granite	22,032	892	3,713	881	5,832	
Madison	60,990	5,972	89,918	4,549	27,655	
Ravalli	35,912	6,804	14,637	3,200	59,808	
Silver Bow	7,405	614	4,117	772	6,008	
Correct for percentage of area in each county contained in Big Hole Watershed						
County	**County Area[1] Correction**	**Cattle**	**Hogs**	**Sheep**	**Horses**	**Poultry**
Beaverhead	35.19%	33,719	990	35,558	2,374	5,414
Deer Lodge	43.70%	2,452	444	4,225	245	3,672
Granite	0.39%	86	3	14	3	23
Madison	5.65%	3,446	337	5,080	257	1,563
Ravalli	0.63%	226	43	92	20	377
Silver Bow	39.03%	2,890	240	1,607	301	2,345
	TOTAL	**42,819**	**2,057**	**46,577**	**3,200**	**13,392**
	Adjust for Watershed Area[2]	38,537	1,851	41,920	2,880	12,053
	Convert to GWLF Animal Units[3]	27,297	1,311	29,693	2,040	8,538
	Round	**27,300**	**1,310**	**29,690**	**2,040**	**8,540**

[1]County percentages taken from STEPL model data server
[2]Big Hole Watershed area = 2,762 mi^2; Melrose gage area = 2,476 mi^2 (e.g. 0.90 conversion)
[3]Assume 1/2 of animals are offspring
each count as 1/4 mature animal (0 at birth 1/2 at weaning)
on landscape 1/2 year (March-September)

Table A3-2: 2002 CENSUS OF AGRICULTURE (USDA, 2004)

MONTANA COUNTY DATA INVENTORY							
County	**Cattle**	**Hogs[1]**	**Sheep**	**Horses**	**Poultry**		
Beaverhead	135,926	15	15,823	2,679	295		
Deer Lodge	8,739	0	1,065	378	0		
Granite	21,737	100	457	881	396		
Madison	70,892	0	4,803	2,526	947		
Ravalli	33,846	854	4,473	4,927	2,319		
Silver Bow	5,937	40	291	758	68		
Correct for percentage of area in each county contained in Big Hole Watershed							
	County Area[2]						
County	**Correction**	**Cattle**	**Hogs**	**Sheep**	**Horses**	**Poultry**	
Beaverhead	35.19%	47,832	5	5,568	943	104	
Deer Lodge	43.70%	3,819	0	465	165	0	
Granite	0.39%	85	0	2	3	2	
Madison	5.65%	4,005	0	271	143	54	
Ravalli	0.63%	213	5	28	31	15	
Silver Bow	39.03%	2,317	16	114	296	27	
	TOTAL	**58,272**	**27**	**6,448**	**1,581**	**200**	
	Adjust for Watershed Area[3]	52,445	24	5,804	1,423	180	
	Convert to GWLF Animal Units[4]	37,148	17	4,111	1,008	128	
	Round	**37,150**	**20**	**4,110**	**1,010**	**130**	

[1]Values in grey estimated; data withheld to avoid disclosing information for individual farms
[2]County percentages taken from STEPL model data server
[3]Big Hole Watershed area = 2,762 mi^2; Melrose gage area = 2,476 mi^2 (e.g. 0.90 conversion)
[4]Assume 1/2 of animals are offspring
each count as 1/4 mature animal (0 at birth 1/2 at weaning)
on landscape 1/2 year (March-September)

Table A3-3: Estimated Livestock Distributions of TMDL Watersheds

Use area of grassland in watershed to distribute farm animals							
Watershed		**Grassland area (ha)**	**Cattle**	**Hogs**	**Sheep**	**Horses**	**Poultry**
Melrose gage		221830	37150	20	4110	1010	130
Willow Cr		1187	200	0	20	10	0
Lost Cr		1132	190	0	20	10	0
Camp		4822	810	0	90	20	0
Wickuip		505	80	0	10	0	0
Soap		1650	280	0	30	10	0
Divide		11500	1930	0	210	50	10
Jerry		1210	200	0	20	10	0
Steel		7902	1320	0	150	40	0
Francis		3041	510	0	60	10	0
Grose		389	70	0	10	0	0

APPENDIX – A4 MODEL INPUT AND OUTPUT

A4-1 SEPTIC DENSITY ESTIMATES

Septic density estimates were completed using NAIP aerial imagery. Approximate numbers of buildings (and associated septic fields) are shown below.

Watershed	Area (ha)
Melrose	495
Willow	0
Wickiup	0
Francis	0
Steel	10
Jerry	5
Camp	10
Divide	30
Grose	0
Lost	5
Soap	2

A4-2 Stocking Density Calculations

Livestock calculations used in GWLF modeling are detailed below.

Available Data:

National Agricultural Statistics Service data from 1998-2007 (NASS, 2008)

106,900 cows and calves
12,600 ewes and lambs
750 horses (estimated)

Convert to AUM (NRCS, 2003)

Assume:	cow/calf pair	= 1 AUM
	ewe/lamb	= 0.3 AUM
	horse	= 1.25 AUM

Livestock estimate for grazing season (May-October; 6 months)

53,450 pair cattle x 1 AUM x 6	= 320,700 AUM
6,300 pair sheep x 0.3 AUM x 6	= 11,340 AUM
750 horses x 1.25 x 6 =	= 5,625 AUM
	= 337,665 AUM

Carrying capacity estimate

221,830 ha of grassland in watershed
0.61 ha (1.5 acres) per AUM

= 363,656 AUM

Stocking rate less than carrying capacity ☑

A4-3 – Modeling Input and Output Tables

Due to large content DEQ will provide model input and tables upon request.

APPENDIX J
STREAMSIDE VEGETATION NUTRIENT FILTERING FUNCTION

Approaches for allocations to riparian function depend upon riparian filtering and uptake of nutrients. Developed for restored riparian function follows the percent reduction approach, an EPA suggested alternative to traditional load analyses. This approach shows considerable promise in developing allocations as research in other parts of the country provides evidence that allocation of a percent reduction of nitrogen and phosphorus to riparian buffers is a feasible tactic. In a review of the efficacy of buffers in removing nitrogen and phosphorus, numerous investigators have demonstrated marked reductions in delivery of nitrogen and phosphorus to surface waters (Wenger 1999). This included nutrients transported by surface run off and through groundwater.

Grass buffers provide an effective means of filtering phosphorus and nitrogen from surface runoff, preventing delivery to streams. Thirty-foot wide grass buffers removed up to 79% of phosphorus, and 74% of nitrogen from overland flow (**Table 1**). The tendency for an increase in nutrient removal with increased buffer width suggests additional decreases are possible with wider buffers. Note that these buffers were trapping runoff from Concentrated Animal Feeding Operations (CAFOs), which have a greater potential to contribute nutrients than rangeland due to the greater stocking rates. A reasonable assumption is that buffers in rangeland may be capable of filtering a higher proportion of the load because the loading is less likely to exceed the buffer's potential filtering capacity compared to buffers treating contributions from a feedlot.

Table 1: Removal of total phosphorus and total nitrogen from surface runoff by grass buffers (modified from Wenger 1999).

	Total P Removal		Total N Removal	
Study	**15 ft buffer**	**30 ft buffer**	**15 ft buffer**	**30 ft buffer**
Dillaha et al. 1988	71.5%	58%	67%	74%
Dillaha et al. 1989	61%	79%	54%	73%
Magette et al. 1987	41%	53%	17%	51%
Magette et al. 1989	18%	46%	0%	48%

In addition to removing nutrients in surface runoff, buffers supporting shrubs are effective at removing nutrients from subsurface flows, particularly nitrate. A review of studies investigating the efficiency of riparian buffers of varying width found percent removal of nitrate of between 75 and 99%, with buffers between 50 and 200 ft in width (Wenger 1999). In contrast to relations between buffer width and filtering of surface runoff, no clear correlation was apparent between buffer width and extent of nitrogen removal from sub-surface flows.

An investigation of the extent of nitrogen removal from surface and subsurface flows within a 50-meter (164 ft) buffer demonstrates the efficiency of riparian buffers at removal of various forms of nitrogen (Peterjohn and Correll 1985). In this investigation, nitrate was present in slightly higher concentrations in groundwater than surface runoff (**Table 2**). Other forms of nitrogen (exchangeable ammonium [NH_4^+] and particulate organic nitrogen) varied between surface and subsurface flow with particulate organic nitrogen being greatest in surface flows by several orders of magnitude. Treatment of both surface and subsurface flows through the 50-meter buffer resulted in a marked reduction of nitrate, the largest nitrogen fraction from subsurface flows, and the second largest from surface flows. In contrast, concentrations of other forms of nitrogen increased after exposure to the buffer. These constituents rose as much as six fold; however, these still comprised a relatively small proportion of the overall nitrogen load, leaving a substantial net decrease in nitrogen loading from exposure to a riparian buffer.

Table 2: Nitrogen reductions in surface and subsurface flows through a 50-meter riparian buffer (Peterjohn and Correll 1985, as presented in Wenger 1999).

		Nitrate (mg/L) (Percent Change)	***Exchangeable NH_4^+ (mg/L)***	***Particulate Organic N (mg/L)***
Surface Runoff	Initial	4.45	0.402	19.5
	Final	0.91 (-79%)	0.087 (-78%)	2.67 (-86%)
Subsurface Transect 1	Initial	7.40	0.075	0.207
	Final	0.764 (-90%)	0.274 (+ 365%)	0.267 (+ 129%)
Subsurface Transect 2	Initial	6.76	0.074	0.146
	Final	0.101 (-99%)	0.441 (+596%)	0.243 (+ 166%)

Applying the principles of measurable reductions of nitrogen and phosphorus in riparian buffers in developing allocations has promise, although several matters need attention. One issue is the relative permanence of the nutrient removal, which differs between nitrogen and phosphorus. Nitrogen removed by riparian forests has two potential fates, incorporation into plant tissue, and denitrification where plants and microbes release nitrogen as gas to the atmosphere. These factors result in permanent or long-term removal of nitrogen from the aquatic system. In contrast, riparian buffers are short-term sinks for phosphorus. Its fate in riparian buffers include uptake by vegetation, adsorption onto soil or organic matter, or release into the stream or groundwater (Lowrance et al. 1998). Once phosphorus saturates the riparian area, the excess is exported as soluble phosphate. Therefore, the riparian buffer will be less efficient at the removal of phosphorus over the long term if grazing and/or fire is not managed to reduce climax conditions while assuring riparian area health.

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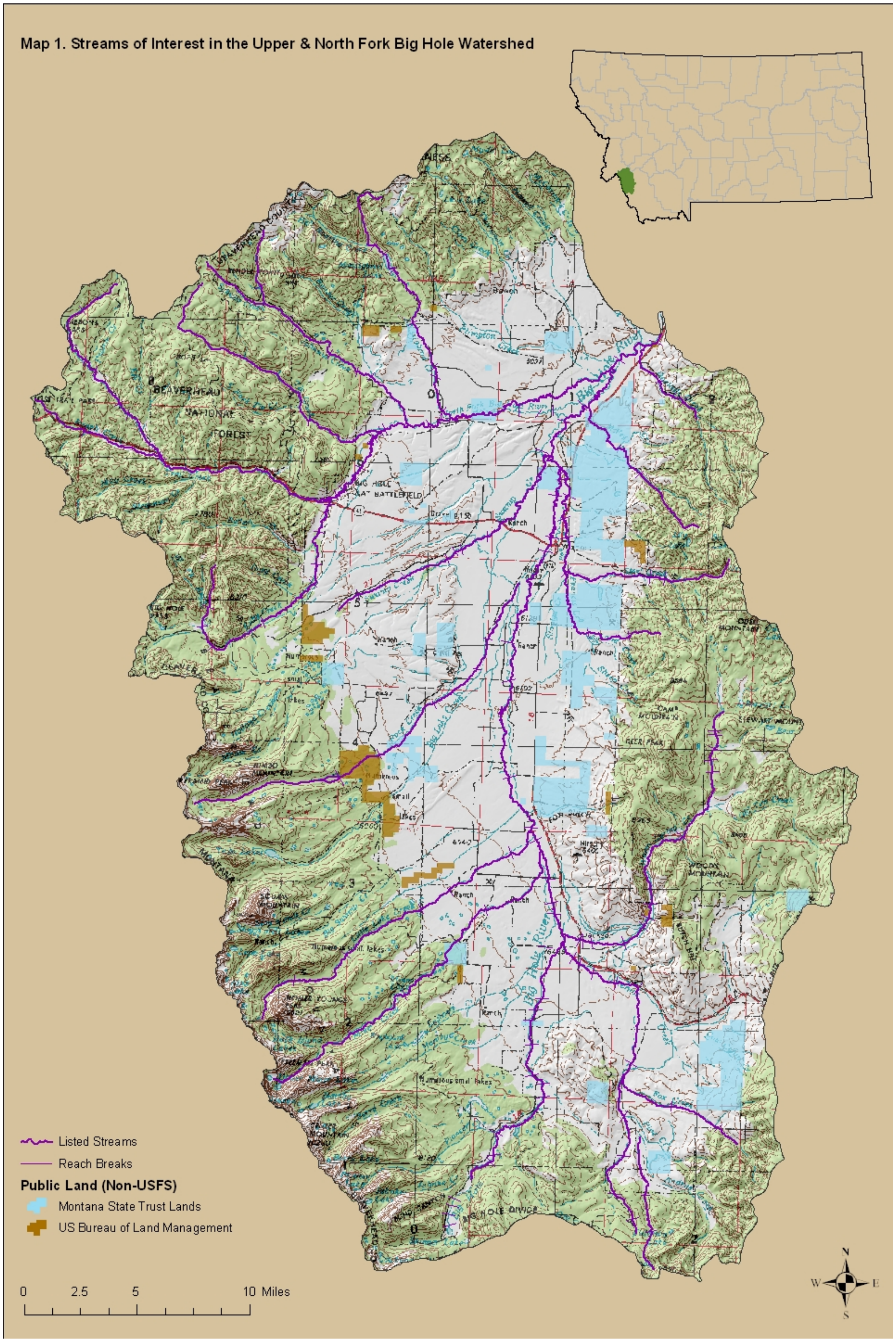
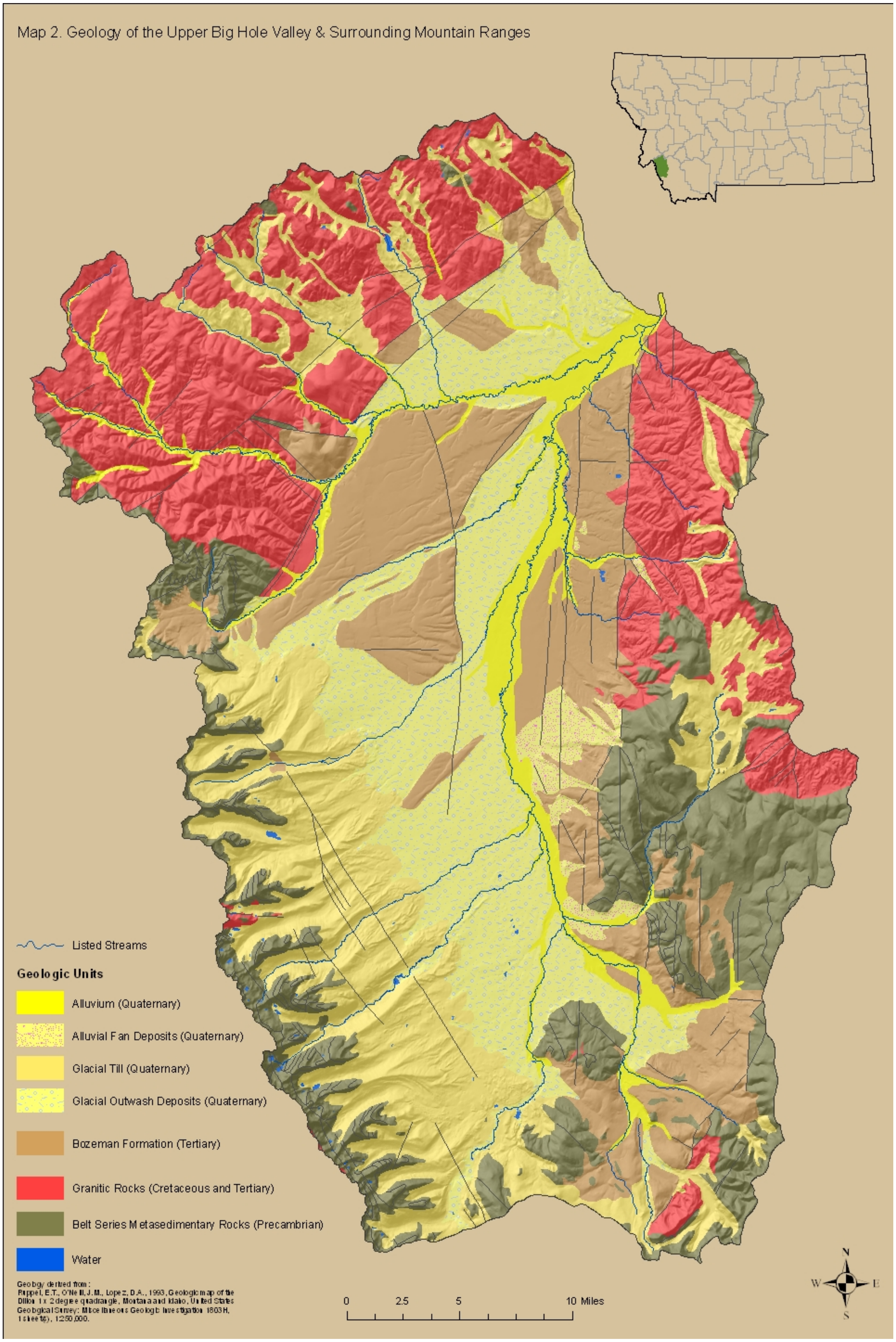
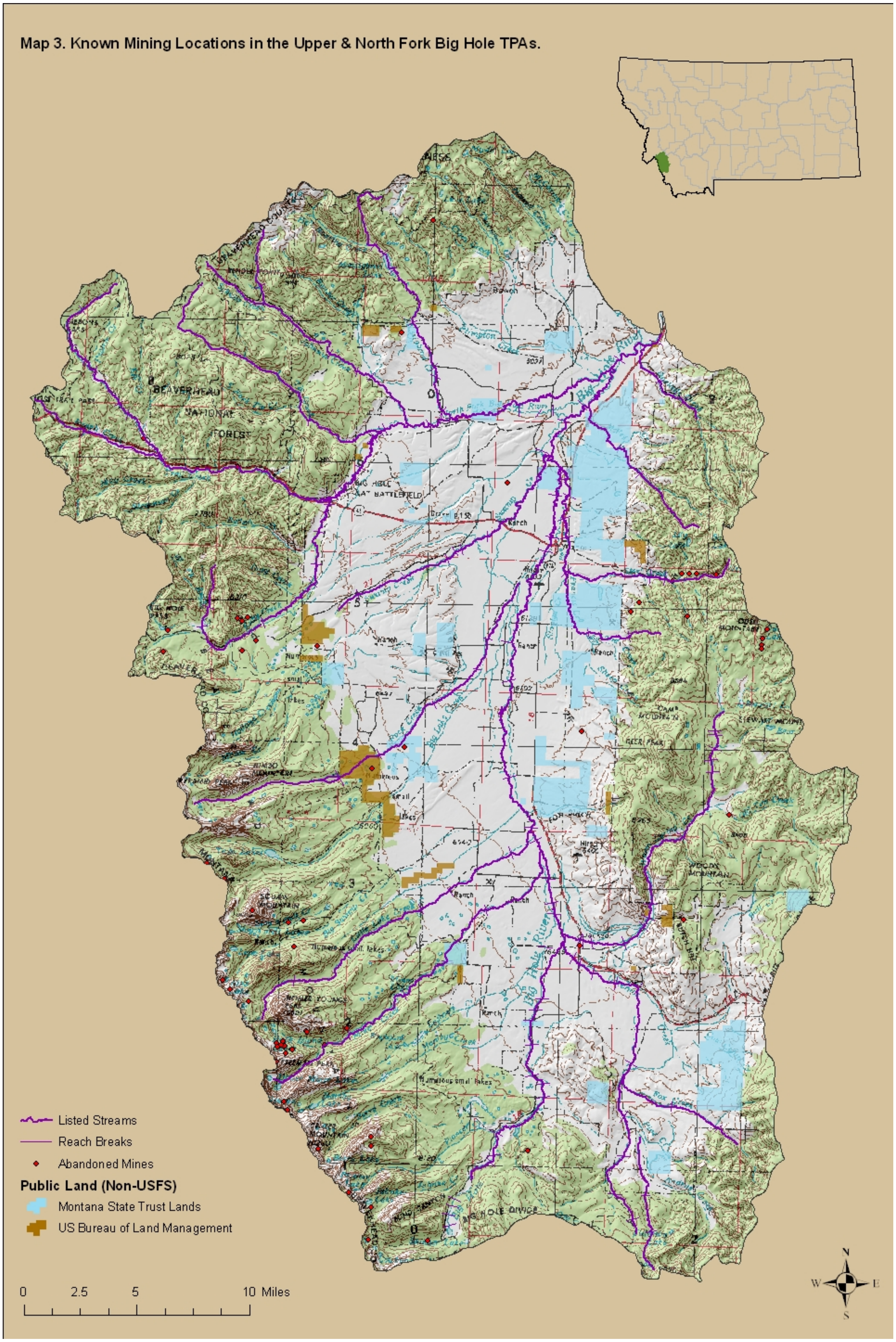
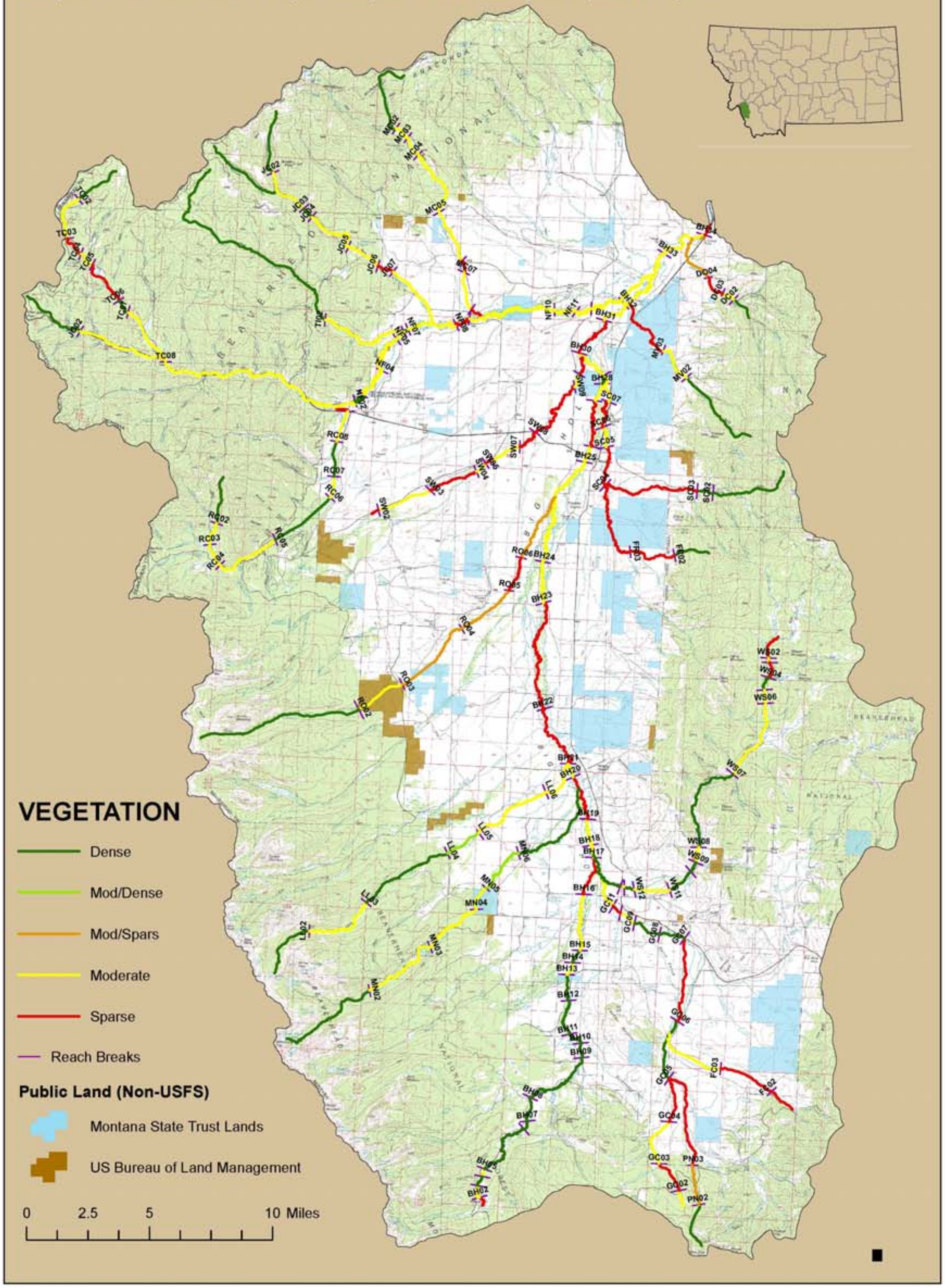
APPENDIX K
UPPER AND NORTH FORK BIG HOLE RIVER PLANNING AREA TMDL MAPS




Map 2. Geology of the Upper Big Hole Valley & Surrounding Mountain Ranges
Listed Streams
Geologic Units
Alluvium (Quaternary)
Alluvial Fan Deposits (Quaternary)
Glacial Till (Quaternary)
Glacial Outwash Deposits (Quaternary)
Bozeman Formation (Tertiary)
Granitic Rocks (Cretaceous and Tertiary)
Belt Series Metasedimentary Rocks (Precambrian)
Water
Geology derived from:
Ruppel, E.T., O'Neill, J.M., Lopez, D.A., 1993, Geologic map of the Dillon 1 x 2 degree quadrangle, Montana and Idaho, United States Geological Survey: Miscellaneous Geologic Investigation 1803H, 1 sheet(s), 1:250,000.
0
2.5
5
10 Miles
N
W
E
S


Map 3. Known Mining Locations in the Upper & North Fork Big Hole TPAs.
Listed Streams
Reach Breaks
Abandoned Mines
Public Land (Non-USFS)
Montana State Trust Lands
US Bureau of Land Management
0 2.5 5 10 Miles
N
S
W
E

Template 4. Estimated levels of riparian vegetation cover using aerial photo analysis.



APPENDIX L
RESPONSE TO PUBLIC COMMENTS

As described in **Section 12.0**, the formal public comment period for the Upper and North Fork Big Hole River TMDLs extended from December 15th, 2008 to January 16th, 2009. Three individuals/organizations submitted formal written comments during the public comment period. Excerpts of the comments have been organized by primary topic heading in this section. Responses prepared by DEQ follow each of the individual comments. The original comment letters are located in the project files at DEQ and may be reviewed upon request.

1. General TMDL Process and Considerations

Comment 1.1: How were "streams of interest" selected? It seems many streams were omitted from evaluation, such as Big Lake Creek, Little Lake Creek, Hamby Creek, and Big Swamp Creek among others. What can one assume about the condition of non-selected streams?

> **Response 1.1:** **Section 3.2** was amended to review the rational that follows.

Category five of the Montana's Integrated Water Quality Report (303d assessment) drives the scope of each TMDL project. Some streams within this TMDL planning area do not have sufficient information for 303d assessment or have been deemed as fully supporting all uses and meeting water quality standards and therefore may not be mentioned in this report. See Montana's Integrated Water Quality Report to determine the status of 303d assessment for streams not addressed within this document. If streams can not be found through a search on the csaic web site, then insufficient information is available for the 303d assessment. (http://www.deq.state.mt.us/wqinfo/303_d/what_is_303d.asp and http://cwaic.mt.gov/)

2. Targets and Existing Conditions

Comment 2.1: The various sediment targets include width/depth ratios, pebble counts (% fines), understory shrub cover along greenline, and length of channel (expressed in terms of # of bank full widths) per pool. It's unclear how this will be applied on the Beaverhead Deer-Lodge National Forrest (BDNF). Apparently the field work done in 2004 assessed these sediment targets, and whether they were attained. A display of streams on the BDNF that do not currently meet these targets would help us focus our efforts. Monitoring results supplied by the BDNF will help display attainment of targets.

> **Response 2.1:** The data summary tables provided in **Section 5** correspond to stream segments identified on **Maps 1 or 4 in Appendix K**. If more precise data locations are needed please contact DEQ for a project database or use information provided in **Appendix C** which provides a data summary.

3. Source Assessment, TMDLs and Allocations

Comment 3.1: While sediment allocations are not parsed out by ownership, there is mention that removal of beaver, loss of riparian function, willow removal, reduced haying/intensive pasturing, and diversions play major roles in sediment exceedances. While the BDNF is not completely immune from these actions, it could be argued that these activities occur largely outside of the BDNF boundary.

> **Response 3.1**: Loss of riparian function, willow removal, haying/intensive pasturing, unpaved roads, diversions and removal of beaver all have the potential to affect in-stream sediment conditions. In limited locations, USFS riparian graze and browse recommendations are not being met. Erosion from unpaved roads may impact localized conditions along streams in mountainous areas. Also, in limited locations irrigation diversions for private lands are diverted on USFS land. Beaver trapping on USFS land is permitted without regard to beaver management. Yet, at a general level, the argument above is correct.

Comment 3.2: Sediment Load Allocations don't display what portion the BDNF is responsible for, though mention of this occurs in broad terms. This might better define where we need to focus our efforts. There is acknowledgement that allocations (% reduction) do not account for BMPs already in place. There is mention of this within the adaptive management section, but that is not part of the Draft. While there is acknowledgement in a narrative fashion of BMPs put in place on BDNF lands, no adjustment to allocations have been made. The road sediment modeling doesn't break out the portion of sediment derived under BDNF ownership. The BDNF recognizes a role of supplying information which further defines the improvements to roads. If the BDNF has already implemented adequate BMPs on roads they are responsible for, then how do we achieve further reductions as defined under Sediment Load Allocations? The incentive for reducing sediment inputs before an approved TMDL is released should not be diminished by not recognizing those accomplishments. A display of what a reduction in road-related sediment would accomplish in the overall sediment reduction budget would provide context with other analysis and allocations that state overall, unpaved roads account for <1% of sediment yield. Please consider displaying a "% of total" for each source. In addition, describing the process used for sampling and analysis could lead to a better understanding of the results.
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> **Response 3.2:** Allocations are provided at a watershed scale within each TMDL. DEQ urges BDNF to coordinate with the Big Hole Watershed Committee (BHWC) to provide a more detailed plan to address restoration approaches within each watershed through a locally lead Water Quality Restoration Plan (WRP). The WRP will consider the technical findings within the TMDLs and will provide a more detailed approach for watershed restoration efforts.
>
> The allocations do account for a general condition of BMPs across the whole landscape of the Upper Big Hole Valley and surrounding mountains. Numeric allocations do not reflect detailed considerations at each tributary scale if BMP implementation differs greatly from the whole Upper Big Hole Watershed. Written qualifiers were incorporated into the sediment source assessment and allocation sections for each watershed when general information about BMP implementation was included in watershed narratives provided by the USFS to DEQ during the TMDL project. The USFS conducted the

unpaved road monitoring on USFS lands via an MOU with DEQ. USFS personnel involved with the project at that time were provided with a draft road analysis report for comment and feedback on 8/22/06. DEQ received no feedback at that time.

Without a much more detailed monitoring effort or more detailed feedback from the USFS with specific information about completed BMPs within each watershed, a more detailed numeric allocation approach is not feasible. DEQ urges BDNF to coordinate with the BHWC during formation of the upcoming WRP to address a more detailed approach of where restoration activities have occurred in the recent past and where restoration funding should be prioritized during future efforts. If USFS can provide detailed information about previously implemented BMPs specific to reducing pollutant loads in the watersheds where TMDLs were written, the information will be identified in the WRP and may be useful for future TMDL reviews.

DEQ provides sediment allocations as a percent reduction by source because the estimated sediment loads from each type of assessment (roads, bank erosion, and upland) depends upon different techniques of monitoring, modeling and associated assumptions. Therefore, caution should be used when comparing sediment loads between categories of sources which depend upon the differing assessment techniques. Also, some sources are localized within a specific area of the watershed and localized in-stream sediment impacts may occur when overall loads at a watershed scale appear to be small. A "percent of total" TMDL reduction by source is not provided because of these rationales.

Sediment source assessments are described in **Sections 8.2.1** through **8.2.5**. Detailed reviews of each type of sediment source assessment were provided in **Appendices A, H and G** and were referenced in **Sections 8.2.1** through **8.2.5**.

Comment 3.3: Silvicultural practices are listed as a source of sediment on many of the streams. The Draft states that timber sales are not targeted for reduction-based allocations, only "no increases" allowed. This appears as a discrepancy that may prove to be a "red flag" during legal review of proposed timber harvest activities. The BDNF proposes the following narrative that recognizes the opportunity for silvicultural practices to occur in a tightly controlled manner where a low probability of sediment delivery exists: "No modeled increase in sediment delivery", with a footnote that the model may not account for extraordinary storm events that may lead to a remote potential for sediment delivery.

Response 3.3: This allocation applies to ground disturbance or vegetation clearing activities associated with timber harvest activities and does not consider associated roads. Associated roads would fall under the unpaved road sediment allocations. DEQ recognizes the need for future silvicutural practices to occur with all reasonable land, soil and water conservation practices in place. The recommendation provided in comment 3.3 falls in line with this approach. The "no modeled increase" recommendation will be incorporated into the sediment allocations.

<u>**Comment 3.4:**</u> Another recognition that the BDNF would like to see is the research that compares the risk of soil erosion and sediment delivery from fuels treatment activities and catastrophic fire (Elliot W., Robichaud P., *Comparing Erosion Risks from Forest Operations to Wildfire*, 2001). This paper displays the role that proper management actions can have in reducing the long-term erosion/sedimentation budget where uncharacteristically high fuel loadings/fire potential exists.

> <u>**Response 3.4:**</u> Recently, much attention has been devoted to this topic in the Northwest US. Historically, timber harvest and large scale fire suppression efforts have occurred for much of a century in a majority of the forested areas. Recently, less fire suppression, a warming trend, biological factors and the lacking ability of the USFS to manage fuels have culminated to provide conditions where fires are influencing large portions of the forested landscape in the Northwest US. Results from Elliot W., Robichaud P., *Comparing Erosion Risks from Forest Operations to Wildfire*, 2001 indicates overall erosion rates may be lower or equal to natural fire regimes when implementing harvest management and/or prescribed fire in a watershed This study does not consider spatial and temporal sediment production considerations in the assessment. Changes in temporal and spatial sediment production likely have impacts upon beneficial uses. Effects of fire are considered in the upland sediment source assessments and attributed to natural loads. The potential affects from fire upon in-stream sediment conditions are noted in **Section 5**. Language about how fire and timber harvest affect sediment production and how fire was considered in the TMDL source assessment was added to **Section 8.3**.

<u>**Comment 3.5:**</u> It's understood that the allocation of sediment from eroding stream banks accounts for potential stream type and associated vegetation communities. A concern exists if allocations were based on conditions assessed on private lands, and then applied throughout the watershed. This could misrepresent conditions where stream reaches are rocky and/or do not receive grazing pressure or other disturbances. The map which shows estimated levels of riparian vegetation cover using aerial photo analysis displays very few reaches on the BDNF with "Sparse" or "Moderate/Sparse" compared to reaches downstream of the BDNF boundary. Breaking out the analysis by ownership, as suggested for roads, may better reflect conditions on the BDNF and allow us to recognize areas that need improvement. The BDNF also recognizes its role of providing site-specific information were clarification is needed.

> <u>**Response 3.5:**</u> Both vegetation conditions and stream type were considered during the selection of field assessment sites and during the bank erosion extrapolation process. Stream type and vegetation condition breaks usually coincided near land ownership boundaries in this TPA. The extrapolation process did not consider land ownership boundaries but the process does address the concerns raised in comment 3.5 because vegetation density conditions and stream channel types were both considered during the extrapolation process. Rock dominated stream channels were compared to each other and low gradient streams were compared to similar low gradient streams for extrapolation without regard to land ownership. See page 7-8 of Appendix H for a description of how bank erosion rates were extrapolated from measured sites to the remainder of the watershed.

<u>Comment 3.6:</u> The allocation based on upland erosion mentions agricultural practices (grazing, hay ground, etc.) and forested areas. Research has shown that any erosion associated with silvicultural practices (and any possible sediment delivery) usually diminishes to pre-disturbance levels after three years. Ongoing monitoring of soils by BDNF staff will help frame this. Conversely, agricultural practices occur year after year, and typically constitute chronic sources. The BDNF sees a need to display consistency in regards to effects from silvicultural practices versus other activities on uplands throughout the TMDL.

> **<u>Response 3.6:</u>** Wording was added to **Section 8.2.3** to address this comment. "Timber harvest has the potential to for transient short term (3-5 years) increases in sediment loading if located near streams. Agricultural activities such as grazing and hay production provide more persistent sediment loads over many years although hay production may produce higher short term loads when reseeded or rotated to alfalfa."

<u>Comment 3.7:</u> All listed streams are described from the headwaters to the mouth. Many of the streams on the BDNF exist within roadless areas or areas of very minimal management actions. For example, while boundaries for livestock grazing may be displayed through GIS on many of these headwater areas, primary range exists only on the lower end of the watersheds. Relying on broad-scale GIS analysis may prove to be problematic. The BDNF recognizes the extra work required to break stream reaches by ownership. However, this may prove useful by better illustrating where emphasis is needed to achieve water quality goals. The BDNF would need to provide watershed specific information where available to better define the existing condition.

> **<u>Response 3.7:</u>** TMDLs are provided for watersheds which contribute pollutants to impaired water bodies. Where information was provided by the USFS, spatial considerations about sources were incorporated into the text of the existing conditions review, TMDL and allocation sections. Detailed information about range use was not provided by the USFS during the project timeframe, only the amount of watershed area within an active grazing allotment.

<u>Comment 3.8:</u> Doolittle – It appears that sediment condition is a worse-case scenario on relatively short reach. Could agree to TMDL findings, since it acknowledges improvement and would continue monitoring.

> **<u>Response 3.8:</u>** Comment noted.

<u>Comment 3.9:</u> Fox – No TMDL. Agree with findings.

> **<u>Response 3.9:</u>** This comment is incorrect. A TMDL for Fox Creek was completed in the draft public comment document.

<u>Comment 3.10:</u> Governor – TMDL. Agree with findings.

> **<u>Response 3.10:</u>** Comment noted.

<u>Comment 3.11:</u> Johnson – Appears to be based on narratives and assumptions. States most sediment is natural or from cattle. This allotment (Tie-Johnson) receives light use from cattle, with limited time spent on BDNF due to cattle not preferring to occupy allotment (pers. con. Kevin Greenwood, Range Conservationist, Wisdom RD, BDNF). The BDNF recognizes the need to release implementation monitoring data to help support assessments.

> **<u>Response 3.11:</u>** The sediment source assessment and TMDL for Johnson Creek are based upon analysis and monitoring reported in Appendices A, C, G and H. No grazing allotment implementation monitoring was received from the BDNF. **Section 8.3.6** was modified to include the professional judgment provided in **comment 3.11**.

<u>Comment 3.12:</u> Joseph – No TMDL. Agree with findings.

> **<u>Response 3.12:</u>** This comment is incorrect. A TMDL for Joseph Creek was completed in the draft public comment document.

<u>Comment 3.13:</u> NF Big Hole – Mentions sediment deposition could be partially natural and also from past activities within the forested mountains. Seems ambiguous, based on assumptions.

> **<u>Response 3.13:</u>** The referenced text was deleted from **Section 5.8.1**. Sediment source assessments are described in **Sections 8.2.1** through **8.2.5**. Detailed reviews of each type of sediment source assessment were provided in **Appendices A, H and G** and were referenced in **Sections 8.2.1** through **8.2.5**.

<u>Comment 3.14:</u> McVey – Mentions potential risks on BDNF for increased sediment delivery, but is this based on data or assumptions? It seems to imply that sediment effects (embedded substrate) occur mainly on private land. Again, does a distinction need to be made between BDNF and private?

> **<u>Response 3.14:</u>** Potential sources of human caused sediment are identified in **Section 5.9**. Sediment source assessments are described in **Sections 8.2.1** through **8.2.5**. Detailed reviews of each type of sediment source assessment were provided in **Appendices A, H and G** and were referenced in **Sections 8.2.1** through **8.2.5**.
>
> In general, grazing has the most sediment and stream channel related impacts on State owned lands and private lands in this watershed. BDNF grazing allotment monitoring data was not provided in the BDNF watershed data compilations provided to DEQ during the project.

<u>Comment 3.15:</u> Miner – Sediment effects appear to be on private, but again no distinction between ownerships.

> **<u>Response 3.15:</u>** Potential sources of human caused sediment are identified in **Section 5.10**. Sediment source assessments are described in **Sections 8.2.1** through **8.2.5**.

Detailed reviews of each type of sediment source assessment were provided in **Appendices A, H and G** and were referenced in **Sections 8.2.1** through **8.2.5**.

In general, only a few small reaches of Miner Creek are impacted by grazing. BDNF grazing allotment monitoring data was not identified in the BDNF watershed data compilations provided to DEQ.

Comment 3.16: Mussigbrod – While some effects to sediment might occur below the dam, most of watershed (above dam) has little management activity. Again, need to make distinction between ownerships.

Response 3.16:. DEQ is using all but the lower 3 to 4 miles of Mussigbrod Creek as a reference condition site for water quality monitoring indication that most of this watershed is managed appropriately. This information was added to **Section 8.3.10**.

Comment 3.17: Pine – Data suggests sediment issues occur below BDNF.

Response 3.17: Some limited grazing impacts were noted on BDNF lands in the Pine Creek Watershed yet most grazing impacts were on private and State lands.

Comment 3.18: Pintlar – States that given low proportion of degraded riparian, the loss of function in a portion of Pintlar Meadows is an unlikely contributor of excess sediment to Pintlar Creek. This is exactly the type of rationale I think is appropriate to apply to other reaches w/in BDNF, but only applied here.

Response 3.18: Comment noted.

Comment 3.19: Rock – Reasons for sediment contributions from BDNF seem arbitrary and capricious: 1) 80% of watershed within allotment. In reality, only a small fraction is used by cattle. 2) "Extensive" multiple use trail system. What data exists to support this? Same with roads that are mentioned. 3) Also mentions presence of brook trout as having an advantage over Westslope Cutthroat Trout on degraded systems. Is this an evaluation criteria (target)?

Response 3.19: The sediment source assessment and TMDL for Rock Creek are based upon analysis and monitoring reported in **Appendices A, C, G and H**. **Section 5.14.1** was edited to consider **comments 3.19.1 and 3.19.2**. Information about trails and roads was provided by BDNF. The type of fish species present and consultation with fisheries biologists are used as supplemental information to the TMDL process but are not used as targets.

Comment 3.20: Ruby – Need data to support claims about multiple use (cattle and roads), and actual effects to sediment. Mentions fine sediment issue in lower reaches (ie. below BDNF?). Need to clarify.

Response 3.20: The information about USFS lands in **Section 5.15.1** was constructed with information provided by the BDNF. No supporting data was provided. **Section**

5.15.1 provides narrative about possible sources and existing conditions. **Section 8.3.14** provides a quantified sediment source assessment, TMDL and allocations.

<u>Comment 3.21:</u> Steel – Meets most targets, except "not fully" for stream-bed sediments. This begs question of how to allocate loads, especially when it mentions effects below BDNF.

<u>Response 3.21:</u> **Comment 3.21** applies only to the Steel Creek monitoring location in the upper watershed on or near USFS lands. The two lower sites indicate impacts to sediment conditions and stream channel. At monitoring reach SC02 near the USFS boundary, the only siltation related results were in pool tails and indicated 100% fines. Therefore, human influenced sources on USFS land should be addressed with all reasonable land, soil and water conservation practices. In general, sources on USFS lands are not as severe or widespread as on private lands in the Steel Creek Watershed but may have localized impacts.

<u>Comment 3.22:</u> Schultz – No TMDL. Though mention of past timber harvest and roads, no effects to sediment. So how is this different from other watersheds where assumptions are drawn which connect timber harvest/roads to sediment. This emphasizes the need to do site-specific evaluation on the ground, accounting for landtype, soils, delivery coefficients, etc.

<u>Response 3.22:</u> Sediment monitoring conducted during the TMDL process collected site specific information to identify in-stream conditions. If in-stream sediment conditions do not meet targets, a TMDL is pursued. If in-stream conditions meet the targets, the TMDL and allocation process is forgone. Data from Schultz Creek met the targets and did not indicate a need for a TMDL.

<u>Comment 3.23:</u> Tie – Mentions timber harvest/roads done in 1960s and 70s. But does that necessarily mean a connection with sediment? The point is, trying to evaluate in-channel sediment and drawing a conclusion based on circumstantial evidence is difficult if not dangerous. Need to accomplish this through the use of "reference watersheds", not merely "reference reaches" as done in developing targets.

<u>Response 3.23:</u> **Section 5.19.1** describes potential human caused sources which may influence sediment conditions. The intent of this section is to identify if human caused sediment sources are present. Sediment source loads are assessed in the Tie Creek sediment TMDL **Section 8.3.17** and in **Appendices A, H and G**.

<u>Comment 3.24:</u> Trail – TMDL. Agree with findings including acknowledgement that conditions are improving, but need to better assess potential conditions. I bring into question that the riparian vegetation assessment rates most of the stream as "moderate". It appears that a robust, recovering vegetation community is providing beaver with the necessary resources to re-establish themselves throughout the system.

<u>Response 3.24:</u> The riparian vegetation assessment referred to was derived from an aerial photo based review of general riparian vegetation condition. The aerial photo assessment provides a course estimate based on aerial photo viewing. Notes from field assessments and results from riparian vegetation monitoring at 5 locations indicate a robust recovering vegetation community except where fire impacted riparian vegetation (**Table 5-21**). This could have been due to affects of heavy moose browse which generally does not kill willows but browse them to snow cover levels during winter. These small shrubs provide excellent rooting which hold stream banks together. Short shrubs are hard to differentiate from grasses during aerial photo reviews. FWP began to more actively manage the expanding moose populations in this area during the TMDL project.

Comment 3.25: Warm Springs – No TMDL, but considered as a source (sediment). The BDNF recognizes the need to link sediment to pool habitat and % fines in spawning channels.

Response 3.25: Comment noted.

4. Temperature and Stream Flow

Comment 4.1: A great deal of my concern is focused on the issue of thermal loading and the possible recommendations and allocations. First, let me state that the word allocation is fairly threatening in that it represents an allotment and allotments have historically been limiting factors. Water rights in and of themselves prove to be very limiting factors and in combination with the seasonal flow variations that affect these high desert valleys. One more restriction could prove very damaging indeed to a low margin industry like agriculture.

Response 4.1: Increasing summer time stream flow within the temperature TMDL is not an allocation. The document was updated to more clearly convey this approach. Wording was added to **Table 7.2** and associated text for clarification. While the term "allocation" may seem threatening, the national TMDL program, which is guided and overseen by the Environmental Protection Agency, mandates the use of the term "allocation" in forming TMDLs. The allocation process is a central principle for forming TMDLs. None of the allocation approaches for the Upper and North Fork Big Hole River TMDLs are built upon assumptions that should be construed to take water rights, reduce hay or cattle production, or affect viability of the ranching community. Allocations were based upon using reasonable land, soil and water conservation practices to alleviate water quality problems. If the restoration approaches are followed, the numeric allocation approaches will likely be met. The results of this process should be used to provide funds from grants to educate landowners about implementing grazing, crop and irrigation practices which will promote better water quality. The same grants can be used to implement these practices.

Additionally, the following wording is included in the document when restoring summer time instream flows is discussed:

> "The allocation strategy and subsequent proposed restoration approaches consider that water rights can not be legally affected by any decisions provided in this document. Therefore, a locally coordinated approach is essential for achieving the goal of increasing summer time instream flows. Increasing thermal assimilative

capacity via instream flow conservation must be accomplished within the sovereignty of Montana's water rights law."

Comment 4.2: The upper Big Hole valley represents one of the greatest water storage assets we have and the limitation of irrigation, or frankly the creation of an over simplified model touting efficiency would likely damage the watershed as a whole. A study completed last summer cites a quick return flow, but that study is very limited to the shallow alluvium in one small area of the valley. A study conducted through the Montana Tech in the late 90's showed considerable upwellings at geological constriction points along the river most likely occurring from a deeper water bearing strata. The more recent study even indicated that deep wells return water until nearly February. It should be noted that even that "short" period extended the return for up to ten days at a critical time. We would likely be entering a crisis period at least a week earlier if not for those flows.

Response 4.2: Ground water and surface water are connected. Irrigation plays a role in the amount of ground water in many areas of the Big Hole River Watershed. The most limiting timeframe in the Big Hole River for both irrigators and aquatic life occurs during the heat of the summer (July-early September). Irrigation efficiencies are only called for during hot weather periods for the temperature TMDLs. The timeframe it takes ground water to return to streams is not easily understood without specific study. The temperature TMDL uses general knowledge about irrigation and ground water influences within the project area. This is because of the scale of the project and difficulty in determining spatially and temporally specific groundwater return timeframes. Therefore, further study should occur to determine time it takes ground water to travel to surface water within specific areas before large scale irrigation efficiency efforts are implemented. Further study should include any consideration of pivots or sprinklers, which may have a large affect upon ground water recharge rates and time of water use associated with water rights. Pivots are not always appropriate for preserving cool stream temperatures, yet may be appropriate in some areas if groundwater return from the irrigated area to streams is naturally delayed until cool weather timeframes when irrigation and evapotranspiration is not occurring within the watershed. **Section 10.4.2.2** was updated with clarifying information about implementation of irrigation efficiencies.

Most of the Montana Tech studies mentioned in **comment 4.2** were considered in the temperature TMDLs and results from each study are reviewed in **Appendix D**. The same upwelling location identified by Montana Tech were found during temperature TMDL monitoring.

Comment 4.3: Already a great deal of water is lost to evaporation and transpiration, and no doubt the water that returns directly to the stream contributes to thermal loading, however; the water that makes it into the alluvium is returned for longer and at a consistent cool temperature. Whereas, "efficient" irrigation would result in the plants using most of the available irrigation and very little return to the water table. We see examples of this in the Gallatin Valley where flood irrigated crop and pasture land have been replaced by pivot irrigation and housing developments. These areas are now faced with a constantly receding water table. There are also indications that the over use of pivots may be damaging the ability of Rock Creek (Phillipsburg) to sustain it's summer flows.

> **Response 4.3**: Comment noted. See response to **Comment 4.2** for an applicable response.

Comment 4.4: My family has been on our ranch at Glen since the 1890's and during that time my great-grandmother, and my grandmother kept journals that not only kept track of day to day activities, but of the natural world. In the pages of these journals I have found references to the river drying up to the point you could walk across it without getting your feet wet (at what is now the near Melrose gauge). These types of entries didn't disappear completely until the 1920's when some of the larger ditch systems began to go in, which certainly suggests a relationship in terms of in stream flow. I will include these with any statement I have on the Lower Big Hole TMDL, however; as today is the deadline I do not have time to retrieve them for the Upper.

> **Response 4.4**: Comment noted. See response to **Comment 4.2** for an applicable response. The following language was added to **Section 10.4.2.2** to address this comment.
>
> > "Early season irrigation should consider both 1) stream flows which are necessary for channel formation and also 2) the ability for irrigation during this timeframe to recharge local aquifers. Spring time aquifer recharge has the potential to increase cool groundwater return flow during the heat of the summer. Irrigation efficiencies during the spring timeframe should not be implemented, unless bank full flood events are needed to scour stream channels and sort sediment within the channel. These two early season irrigation considerations should be balanced in concurrence with each other. Fertilizer application timeframes should also be considered for reducing nutrient runoff if excess water application occurs during high water. "

Comment 4.5: It should also be mentioned that most irrigators in the Upper Big Hole typically only irrigate while they have water, which tends to be during periods of high flow. This fact and the extremely short growing season are limiting factors to types of crops produced and the economic viability of other irrigation systems.

> **Response 4.5**: Comment noted. Hay/pasture was the only "crop" considered as being grown this TPA during the TMDL assessments. Recent efforts to more efficiently irrigate hay and pastures are noted in the restoration section of the document. Economic viability of proposed irrigation systems should be considered along with impacts to groundwater and summer stream flows during specific implementation efforts.

Comment 4.6: I believe it is a mistake to look at this river system in separate pieces when in fact it is a sum of its parts. Changes and recommendations in one part of the system ultimately affect the whole, and while some of the CCAA (candidate conservation agreement with assurances) habitat restoration may positively effect everyone, the efficient or limited irrigation wording could have large negative impacts downstream.

Response 4.6: The state of Montana packages TMDLs into basin wide areas to address watershed sources during the TMDL process. The Big Hole Watershed was addressed in two separate documents because if the large size of the watershed and the large number of TMDLs produced with in the watershed. DEQ agrees that a watershed should be managed as a whole. Upstream and downstream impacts from any proposed activity should be considered prior to instating changes. See responses to **comments 4.1, 4.2 and 4.4 for** further response to this comment.

5. Water Quality Restoration

Comment 5.1: A Fluvial Arctic Grayling CCAA (candidate conservation agreement with assurances) restoration project list was provided by Montana Fish Wildlife and Parks (FWP) during the public comment period. FWP indicated it should be included in **Section 10** prior to the public comment period.

Response 5.1: **Section 10.5** was created to review recent restoration activities. Portions of the table provided by FWP are included within this section.