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E. COLI TOTAL MAXIMUM DAILY LOAD FOR THE MIDDLE FORK CROW CREEK WATERSHED

Topical Report RSI-2570

prepared for

Wyoming Department of Environmental Quality
200 West 17th Street
Cheyenne, Wyoming 82001

May 2016

RESPEC

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by

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Cheyenne, Wyoming 82001

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Total Maximum Daily Load Summary	
Waterbody Name/Description	Middle Fork Crow Creek (A 1.5-mile section of creek at Forest Service (FS) Road 700 crossing)
Assessment Unit I.D.	WYSP101900090101_01
Size of Impaired Waterbody	1.5 miles (2.4 kilometers)
Size of Watershed (Cumulative)	19.5 square miles (50.6 square kilometers)
Location	12-digit Hydrologic Unit Code (HUC): 101900090101
Impaired Designated Use(s)	Recreation
Impairment	*E. coli*
Stream Class	2AB
Cause(s) of Impairment	*E. coli*
Cycle Most Recently Listed	2012
Total Maximum Daily Load Water Quality Targets	Indicator Name: *E. coli* Primary Contact Recreation: Summer Recreation Season: a geometric mean of no less than five samples obtained during separate 24-hour periods for any 60-day period ≤ 126 organisms per 100 milliliters (org/100 mL). These criteria apply from May 1 through September 30. Winter Recreation Season: a geometric mean of no less than five samples obtained during separate 24-hour periods for any 60-day period ≤ 630 org/100 mL. These criteria apply from October 1 through April 30.
Analytical Approach	HSPF, Load Duration Curves

Summer Recreation *E. coli* Total Maximum Daily Load Component (expressed as 10^9 org/day)	**Flow Zone**				
	High	**Moist**	**Midrange**	**Dry**	**Low**
	> 11.8 cfs	11.8—3.5 cfs	3.5—2.3 cfs	2.3—0.6 cfs	< 0.6 cfs
Load Allocation	45.8	25.3	9.5	4.4	1.9
Wasteload Allocation	0.0	0.0	0.0	0.0	0.0
Margin of Safety	8.0	8.3	1.0	2.5	0.1
Total Maximum Daily Load	53.8	33.6	10.5	6.9	2.0

cfs = cubic feet per second

TABLE OF CONTENTS

1.0 INTRODUCTION 1
1.1 CLEAN WATER ACT 303(D) LISTING INFORMATION 1
1.2 WATERSHED CHARACTERISTICS 2
1.2.1 Precipitation 5
1.2.2 Water Use 8
1.2.3 Geology and Soils 9
1.2.4 Elevation and Slope 9
1.2.5 Recreational Use 15
1.2.6 Grazing 15
1.3 DISCHARGE AND WATER QUALITY CONDITIONS 15
1.3.1 Discharge 15
1.3.2 Water Quality 18

2.0 SOURCE ASSESSMENT 24
2.1 BACTERIA SOURCE INVENTORY 24
2.1.1 Point Sources 24
2.1.2 Nonpoint Sources 24
2.2 SOURCE LOAD ASSESSMENT 24
2.2.1 Model Methods 25
2.2.1.1 Gathering and Developing Time-Series Data 25
2.2.1.2 Segmenting and Characterizing the Watershed 25
2.2.1.3 Estimating Bacteria Loads and Modeling Bacteria Accumulation and Storage Rates 28
2.2.1.4 Calibrating and Validating the Model 30
2.2.2 Model Calibration Results 31
2.2.3 Source Assessment 36

3.0 TOTAL MAXIMUM DAILY LOAD AND ALLOCATIONS 37
3.1 LOADING CAPACITY 37
3.2 MARGIN OF SAFETY 37
3.3 WASTELOAD ALLOCATION 38
3.4 LOAD ALLOCATION 38
3.5 LOAD REDUCTIONS TO MEET TOTAL MAXIMUM DAILY LOAD 38
3.6 LOAD DURATION CURVES/TOTAL MAXIMUM DAILY LOAD TABLES 38

4.0 SEASONALITY 40

5.0 PUBLIC PARTICIPATION 42

6.0 MONITORING STRATEGY 43

7.0 REASONABLE ASSURANCE 44

TABLE OF CONTENTS (continued)

7.1 EXISTING WATERSHED MANAGEMENT EFFORTS 44
7.2 EVALUATION OF MANAGEMENT SCENARIOS 44

8.0 REFERENCES 46

APPENDIX A. SUMMARY OF 2015 DATA A-1

LIST OF TABLES

TABLE		PAGE
1-1	Statistical Summary of Stream and River Daily Average Discharge Data Available During Modeling Period	18
1-2	Summer Recreation Season *E. coli* Samples Available, Not Including Replicates	20
1-3	Summer Recreation Season Fecal Coliform Samples, Not Including Replicates	20
1-4	Summer Recreation Season *E. coli* 60-Day Geometric Mean Summary	23
2-1	Subwatershed Metrics	27
2-2	Project Area Livestock Estimates	29
2-3	Wildlife Estimates	29
2-4	Project Area Anthropogenic Estimates	30
2-5	Source Assessment of *E. coli* Load by Flow Regime	36
3-1	Summer Recreation Season Total Maximum Daily Load for Middle Fork Crow Creek	39
7-1	Load Reductions Needed	44
7-2	Percent Reductions From Simulated *E. coli* Best Management Practices	45
A-1	Single Sample 2015 *E. coli* Data at NFSR700	A-2

LIST OF FIGURES

FIGURE		PAGE
1-1	Middle Fork Crow Creek Total Maximum Daily Load Project Area Showing the Impaired Waterbody	3
1-2	Predominant National Land Cover Database 2011	4
1-3	Project Area Land Cover	5
1-4	Average Annual Precipitation (1981–2010) Obtained From The Natural Resource Conservation Services' Geospatial Gateway	6
1-5	Monthly Average Precipitation (2004–2014) From SNOTEL 1045 Site North of the Project Area	7
1-6	Annual Precipitation (2004–2014) From SNOTEL 1045 Site North of the Project Area	8
1-7	Schematic of Pipelines for Municipal Water for the City of Cheyenne	10
1-8	Bedrock Geology	11
1-9	Surface Geology	12
1-10	Hydrologic Soil Groups	13
1-11	Elevations	14
1-12	Grazing Allotments	16
1-13	Discharge and Water Quality Monitoring Stations	17
1-14	Monthly Boxplot of Flow in Middle Fork Crow Creek Above Granite Springs Reservoir 2003–2014	19
1-15	Regression Analysis Relationship Between All Available Paired Fecal Coliform and *E. coli* Samples	22
1-16	Time-Series Plot of *E. coli* Data and Translated Fecal Coliform Data	22
1-17	Boxplot of Monthly *E. coli* Concentrations From All Available *E. coli* Data	23
2-1	Subwatersheds and Reaches	26
2-2	Model Land Cover Representation	28
2-3	General Calibration R and R^2 Targets for HSPF Applications	32
2-4	Simulated and Observed Discharge Above Granite Springs Reservoir	32
2-5	Simulated and Observed Monthly Runoff Above Granite Springs Reservoir	33
2-6	Simulated and Observed Average Annual Runoff Above Granite Springs Reservoir	33
2-7	Simulated and Observed *E. coli* Monthly Concentrations in the Impaired Reach of Middle Fork Crow Creek	34
2-8	Concentration-Duration Curve in the Impaired Reach of Middle Fork Crow Creek	35
3-1	Middle Fork Crow Creek Load Duration Curve Representing Geometric Mean *E. coli* Loads Based on the Summer Recreation Season *E. coli* Target	39

LIST OF FIGURES (continued)

4-1 Load Duration Curve Showing Monthly Variation of Single-Sample-Based Load Exceedance Created Using All *E.coli* Data Without Replicates 40

A-1 Annual Boxplots and Summary Statistics of *E. coli* Data A-3

A-2 Summer Recreation Season 60-Day Geometric Mean Load Duration Curve With 2015 Data A-4

1.0 INTRODUCTION

Section 303(d) of the Clean Water Act (CWA) and the U.S. Environmental Protection Agency (EPA) Water Quality Planning and Management Regulations (40 CFR 130) require states to develop Total Maximum Daily Loads (TMDLs) for waterbodies that do not meet applicable water quality standards or guidelines for the protection of designated uses under technology-based controls. TMDLs specify the maximum pollutant load that a waterbody can receive and still meet water quality standards. Based on a calculation of the total allowable load, TMDLs allocate pollutant loads to sources and incorporate a margin of safety (MOS). TMDL pollutant load reduction goals for significant sources provide a scientific basis for restoring surface water quality by linking the control action development and implementation to attain and maintain water quality standards and designated uses.

The intent of this document is to identify the components of a TMDL, support adequate public participation, and facilitate the EPA review. The TMDL was developed in accordance with Section 303(d) of the federal CWA and follows EPA guidance. This TMDL document addresses the *E. coli* impairment in the Middle Fork Crow Creek Watershed.

Modeling bacteria concentrations and developing a TMDL for the watershed will provide a framework for the Wyoming Department of Environmental Quality (WDEQ) and watershed managers on which to base management decisions. The TMDL will also provide reasonable assurance that the bacteria impairment will be addressed by continued best management practice (BMP) implementation and that future impairments will be readily addressed with an in-place model and TMDL. Furthermore, outcomes from the TMDL, such as increased implementation, will protect the recreational designated uses and will not impair or threaten other designated uses assigned to these waterbodies.

1.1 CLEAN WATER ACT 303(D) LISTING INFORMATION

The Middle Fork Crow Creek Watershed has one impaired segment [WDEQ, 2014] located in the upstream, western portion of the Crow Creek Watershed (Hydrologic Unit Code [HUC] 10190009). The segment was originally listed as impaired for fecal coliform in 2004. In 2008, it was delisted based on data from 2005 through 2007; in 2010, it was listed as impaired for *E. coli*. The state of Wyoming classifies streams into four categories and several subcategories. Each category is protected for specific designated uses. The impaired segment is classified as a 2AB stream.

The WDEQ [2013] states the following regarding Class 2AB waters:

> *Class 2AB waters are those known to support game fish populations or spawning and nursery areas at least seasonally and all their perennial tributaries and adjacent wetlands and where a game fishery and drinking water use is otherwise attainable. Class 2AB waters include all permanent and seasonal game fisheries and can be either "cold water" or "warm water" depending on the predominance of cold-water or warm-water species present. All Class 2AB waters are designated as cold-water game fisheries unless they are identified as a warm-water game fishery by a "ww" notation in the "Wyoming Surface Water Classification List." Unless it is shown otherwise, these waters are presumed to have sufficient water quality and quantity to support drinking water supplies and are protected for that use. Class 2AB*

waters are also protected for nongame fisheries, fish consumption, aquatic life other than fish, recreation, wildlife, industry, agriculture, and scenic value uses.

The WDEQ set the primary contact recreation use *E. coli* target during the summer recreation season as a geometric mean of 126 organisms per 100 milliliters (org/100 mL) during any consecutive 60-day period. To represent the entire 60-day period, the WDEQ requires that a minimum of five samples be collected and that they be separated by a minimum of 10 days. However, the WDEQ recommends collecting more than five samples when resources allow. When more than five samples are collected, samples within 10-day periods must be averaged before being used to calculate the 60-day geometric mean. The summer recreation *E. coli* criteria are applicable from May 1 through September 30. Primary contact recreation is defined in the Wyoming Water Quality Standards [WDEQ, 2013] as "any recreational or other surface water use that could be expected to result in ingestion of the water or immersion (full body contact)." Some examples of primary contact could include swimming, wading, or boating. From October 1 through April 30, all waters are protected for the secondary contact recreation only and the winter recreation season standard, which has an *E. coli* target of a geometric mean of 630 org/100 mL during any consecutive 60-day period as described above. Other applicable water quality standards in the Middle Fork Crow Creek Class 2AB stream segment are summarized in the Wyoming Water Quality Rules and Regulations [WDEQ, 2013]. Water quality standards for Wyoming surface water also include a regulatory policy concerning antidegradation that protects water uses that were in existence on or after November 28, 1975; the level of water quality needed to protect those uses needs to be maintained and protected. To be listed as impaired, a waterbody has to exceed the *E. coli* target more than once in a 3-year period [WDEQ, 2013].

Before 2007, the bacteria criterion was based on a 30-day geometric mean of fecal coliform bacteria as opposed to *E. coli* bacteria. In 2007, it was updated to be based on a 30-day geometric mean of *E. coli* bacteria. It was again changed to the criterion described above (60-day geometric mean of *E. coli* bacteria) in 2013.

1.2 WATERSHED CHARACTERISTICS

For the purpose of this TMDL, the project area is defined as the headwaters of Middle Fork Crow Creek to the outlet of the impaired segment, as illustrated in Figure 1-1. A second boundary illustrated in Figure 1-1 represents the area in which hydrology was modeled. The bacteria portion of the model was at the project area extent. The model for this project is further discussed in Section 2.2. The Middle Fork Crow Creek project area is located in Albany County in the southeastern part of Wyoming. The Middle Fork Crow Creek Watershed above the endpoint of the impaired segment drains approximately 12,509 acres.

The majority of the land cover in the project area is forest (48 percent) and scrub/shrub (44 percent). Other land covers include grasslands, wetlands, and developed land (mainly roads), as shown in Figures 1–2 and 1-3. The land cover summary is based on the 2011 National Land Cover Database (NLCD), a 16-category multilayer land cover classification dataset that is derived from Landsat imagery and ancillary data that provides consistent land cover data for all 50 states [Multi-Resolution Land Characteristics Consortium, 2015]. Categories from the National Vegetation Classification-Subclass Land Uses that occur in the project area mainly include cool temperate forest; temperate grassland, meadow, and shrubland; cool semidesert scrub and grassland; and temperate and boreal freshwater wet meadow and marsh [National

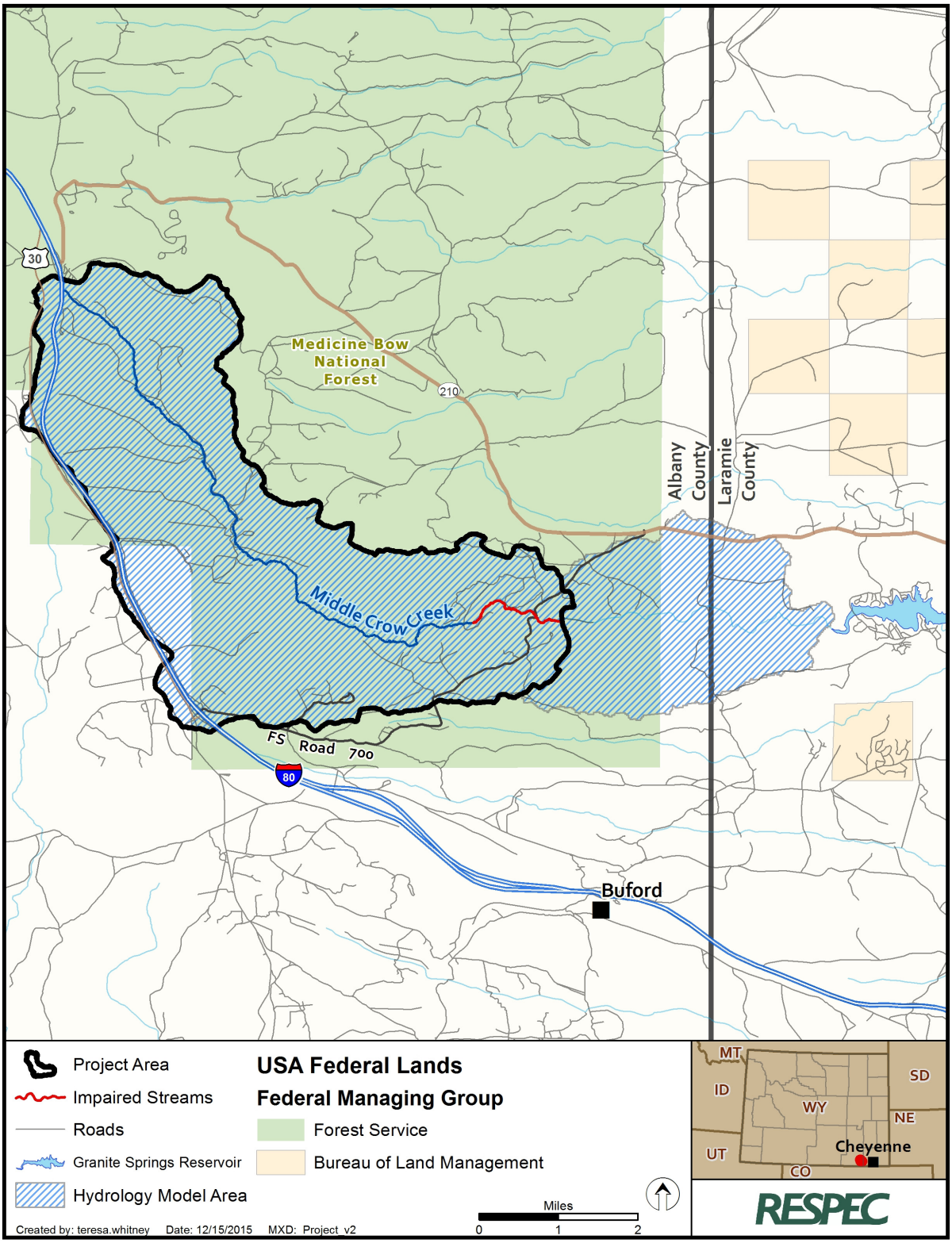


Figure 1-1. Middle Fork Crow Creek Total Maximum Daily Load Project Area Showing the Impaired Waterbody.

Figure 1-2. Predominant National Land Cover Database 2011.

Gap Analysis Program, 2011]. LANDFIRE shows that the predominant vegetation within the watershed consists of Mountain Big Sagebrush, Douglas-Fir, Subalpine-Fir, Engelmann Spruce, Aspen, Rough Fescue, Idaho Fescue, and Cottonwood-Willow community types with some other types including Ponderosa Pine, Limber Pine, and Bluebunch Wheatgrass present in the watershed [LANDFIRE, 2015].

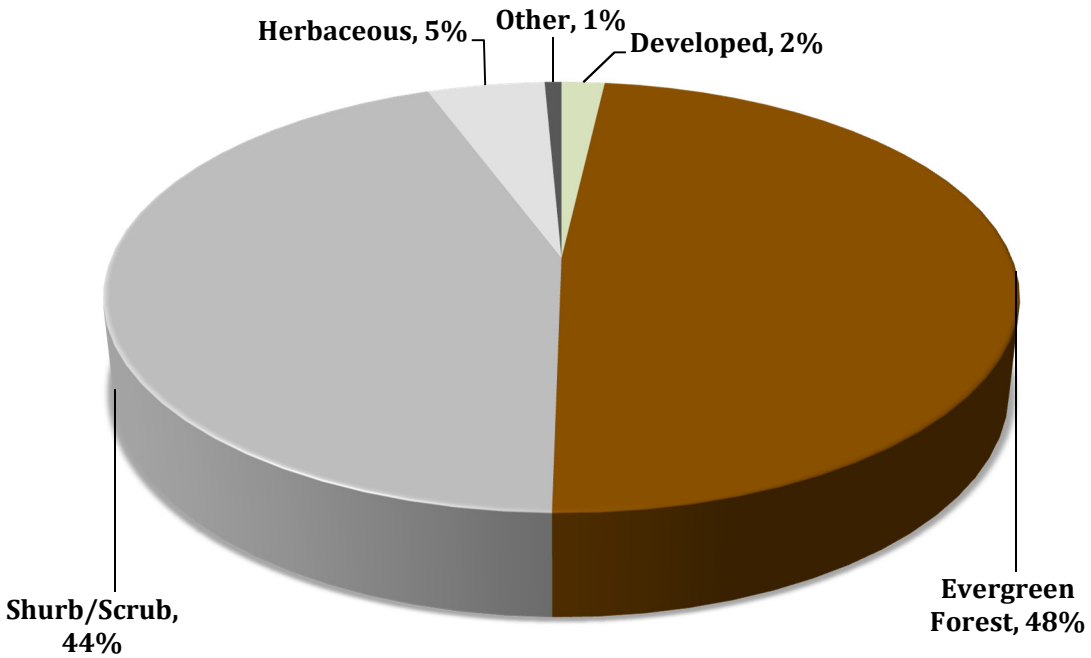


Figure 1-3. Project Area Land Cover.

The project area is primarily located within the Medicine Bow National Forest. Public lands make up approximately 92 percent of the project area and private lands make up the remaining 8 percent. All publicly owned lands in the project area are managed by the U.S. Forest Service (USFS) and are generally grazed during the months of June through October. Between 2004 and 2014, cattle or sheep have been on allotments as early as June 1 and have stayed as late as October 17. The USFS land is also used for recreation (hunting and camping) throughout the spring, summer, and fall. Wildlife such as elk, deer, and beaver are also located within the project area.

1.2.1 Precipitation

Average annual precipitation, as depicted in Figure 1-4, varies greatly throughout the Middle Fork Crow Creek project area and ranges from 19 inches in the southeastern portion to 23 inches in the northwestern portion [Natural Resources Conservation Service, 2012]. Figure 1-5 shows the average monthly precipitation in the project area, which is generally the highest in spring (April, May). Annual precipitation is shown in Figure 1-6.

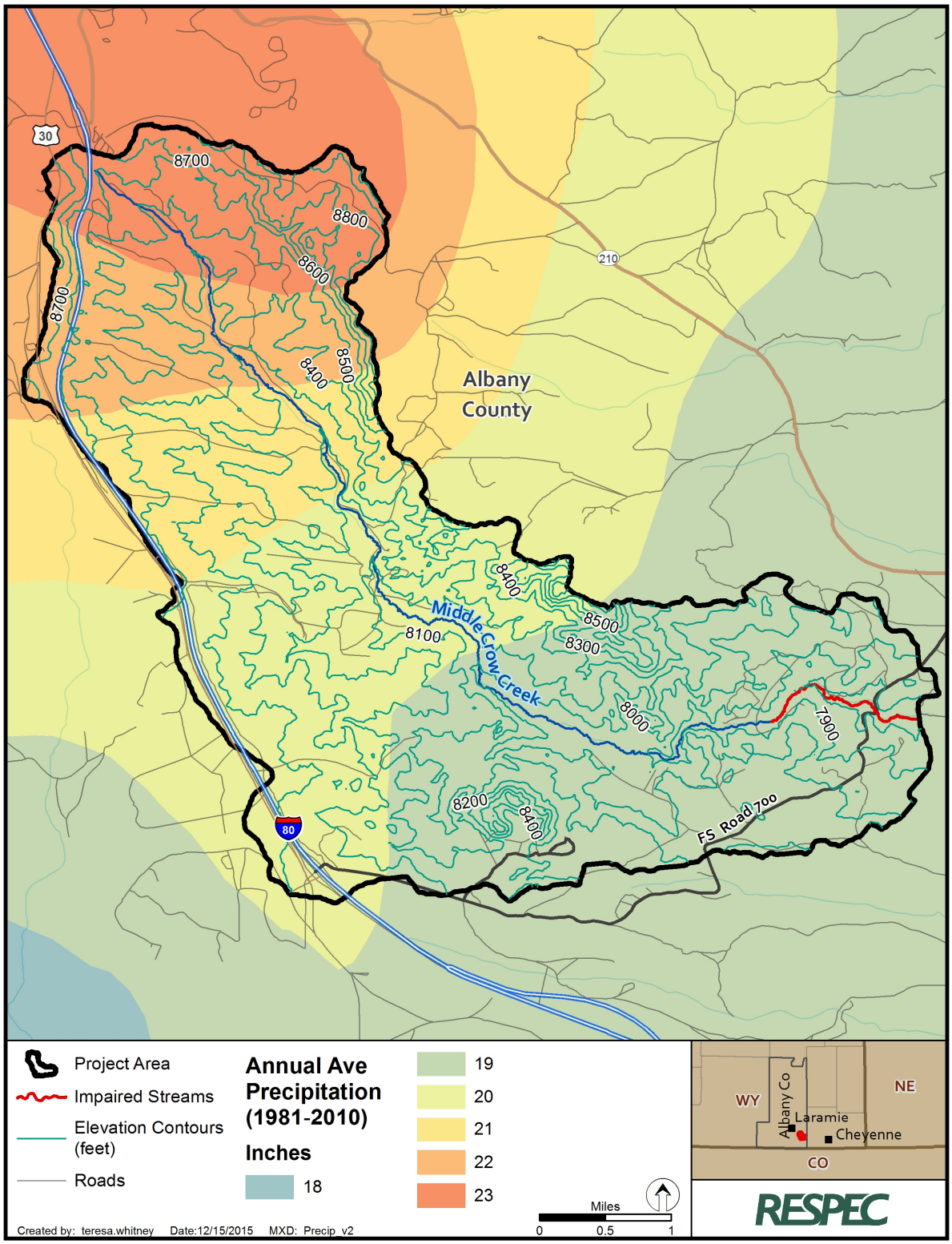
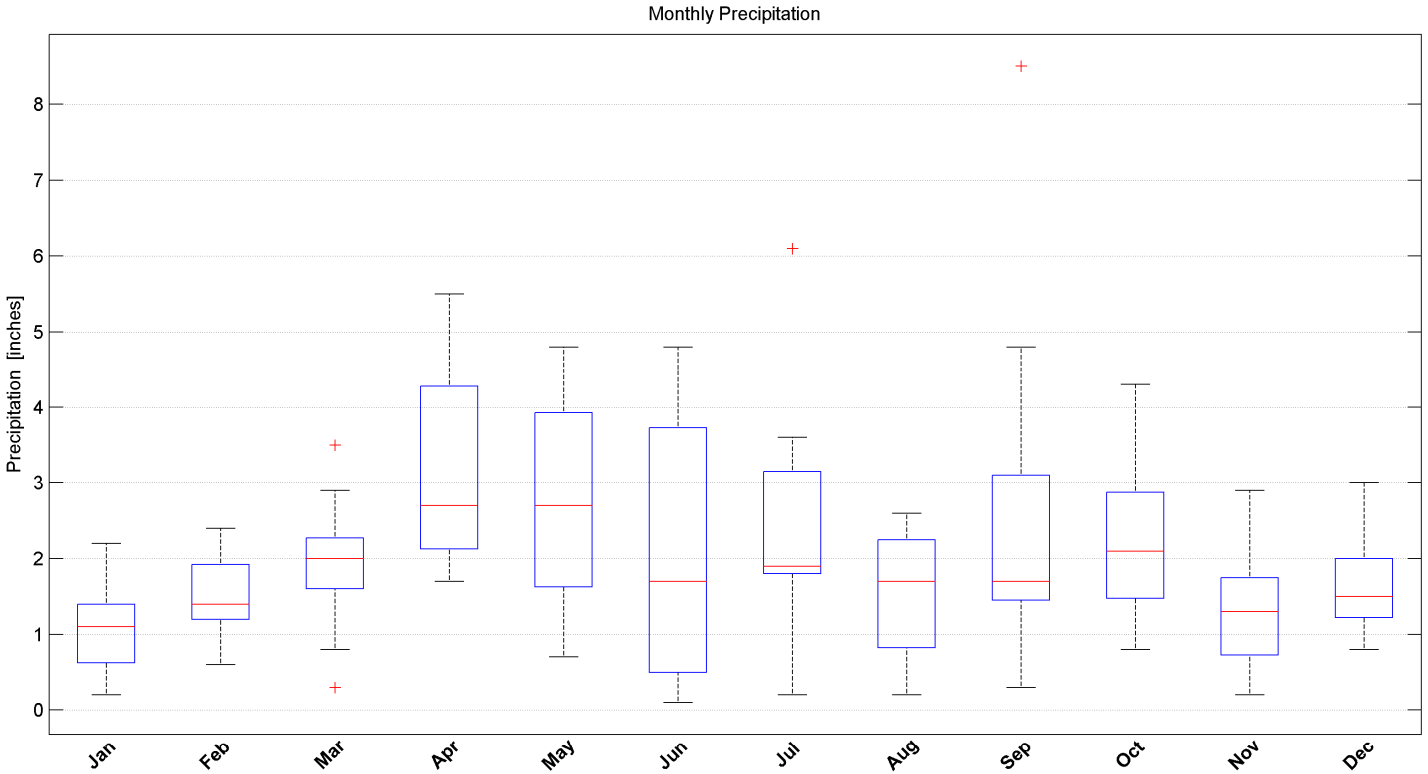


Figure 1-4. Average Annual Precipitation (1981–2010) Obtained From The Natural Resource Conservation Services' Geospatial Gateway [Natural Resources Conservation Service, 2012].



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
n	11	11	11	11	11	11	11	11	11	11	11	11
Min	0.2	0.6	0.3	1.7	0.7	0.1	0.2	0.2	0.3	0.8	0.2	0.8
Max	2.2	2.4	3.5	5.5	4.8	4.8	6.1	2.6	8.5	4.3	2.9	3
25th	0.63	1.2	1.6	2.1	1.6	0.5	1.8	0.82	1.5	1.5	0.72	1.2
Median	1.1	1.4	2	2.7	2.7	1.7	1.9	1.7	1.7	2.1	1.3	1.5
75th	1.4	1.9	2.3	4.3	3.9	3.7	3.2	2.3	3.1	2.9	1.8	2
Mean	1.1	1.5	1.9	3.1	2.7	2.2	2.5	1.5	2.6	2.3	1.3	1.7

Figure 1-5. Monthly Average Precipitation (2004–2014) From SNOTEL 1045 Site North of the Project Area.

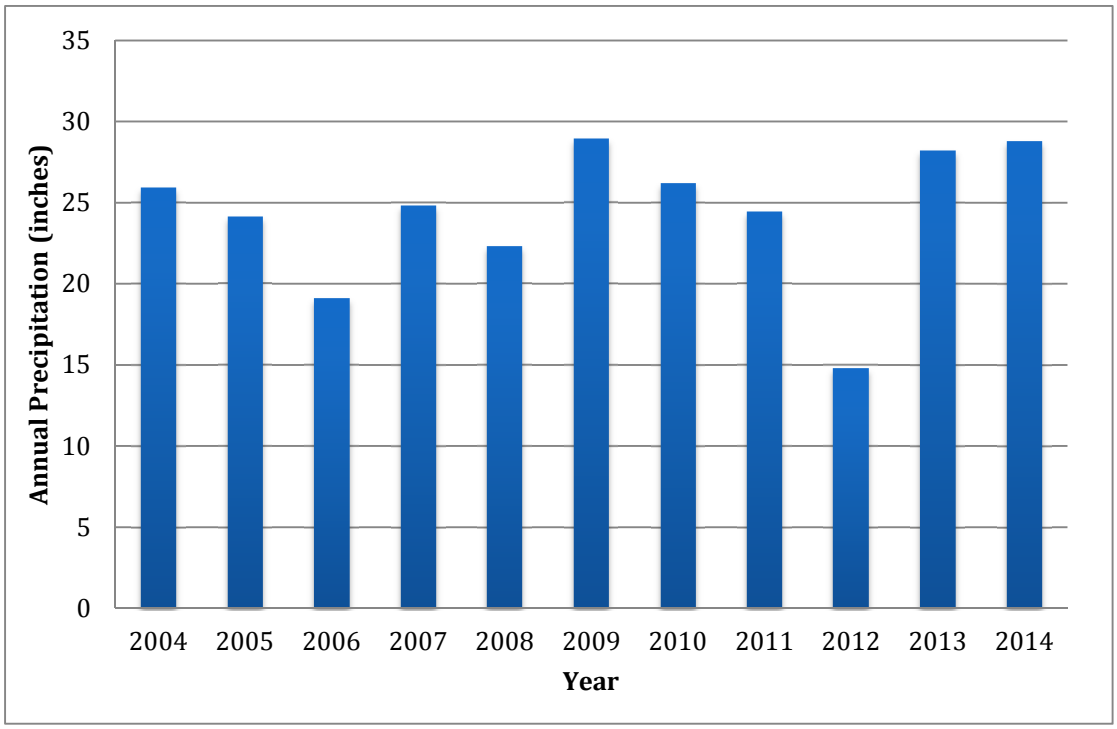


Figure 1-6. Annual Precipitation (2004–2014) From SNOTEL 1045 Site North of the Project Area.

Short-duration, high-intensity rainstorms are common during the summer months. Approximately 55 percent of the total precipitation falls as rain, and the other 45 percent of the total precipitation falls as snow. Precipitation is generally higher in the higher elevations and lower further down toward the city of Cheyenne. This occurs because as air flows west to east, up and over the mountain range, the air parcels will cool and condense, forming clouds on the west (windward) side once it reaches saturation and will precipitate out. Then, as the same parcel begins to descend on the lee (or east) side of the mountain range the parcel will warm up as it sinks as well as evaporate. Because the project area is still in the higher elevation area on the lee side, the precipitation remains heavier. This is known as an orographic effect. Because the cities of Laramie and Cheyenne are at much lower elevations, they also have lower average annual precipitation amounts.

1.2.2 Water Use

There is very little consumptive water use in the project area. Consumptive use includes camping activities (e.g., pumping water from wells in established campgrounds), livestock grazing on USFS lands, and water use for the residents of the watershed (approximately 10 homes) who have private wells. There is a water supply pipeline for municipal water for the city of Cheyenne that flows into the project area and delivers water to a small, unnamed tributary above Granite Springs Reservoir. Rob Roy Reservoir is the original source of the supply for this water-supply pipeline. On its way to Middle Fork Crow Creek, the pipeline has an outlet to the South Fork of the Middle Fork Crow Creek which delivers approximately 2 cubic feet per second (cfs) into North Bamford Creek and South Bamford Creek before it delivers the

remainder of its flow to the unnamed tributary near Devil's Playground in the Middle Fork Crow Creek Watershed. Middle Fork Crow Creek then delivers the water to Granite Springs Reservoir, which subsequently flows into Crystal Reservoir. Crystal Reservoir is the final destination for the municipal water before it is piped to the city of Cheyenne's water treatment facility [Eccleston et al., 2004]. Testing has shown that bacteria is not present in the water being transferred from the pipeline. Figure 1-7 illustrates a schematic of the pipelines flowing from the reservoirs in the west to the Crow Creek Watershed.

1.2.3 Geology and Soils

The Middle Fork Crow Creek watershed is located in the southern end of the Laramie Mountain Range. The area has a complex structural history with complex Laramide-age deformation and uplift. An in-depth discussion of the watershed's geology was beyond the scope of this study; however, general geologic maps and discussions are presented to define the formations present that could potentially impact hydrology.

The bedrock and surficial geology of the area are provided in Figures 1-8 and 1-9. The majority of the project area (92 percent) is underlain by Middle Proterozoic Sherman Granite bedrock. A smaller outcrop of Early Proterozoic metasedimentary and metavolcanic rocks occur in the northwest portions of the project area. A small strip of Casper Formation (Permian-Pennsylvanain age) outcrops in the northwest between I-80 and the edge of the watershed.

The surficial geologic units within the watershed, which are illustrated in Figure 1-9, predominantly consist of slopewash and colluvium, bare bedrock, mixed grus, and minor mixed residuum. These geologic units influence the watershed by providing the parent material and morphology for the soil formations and plant communities within the study area, which affect runoff and infiltration rates.

Approximately 53 percent of the project area has hydrologic group D soils, 22 percent has hydrologic group C soils, 4 percent has hydrologic group B soils, and 20 percent is unclassified. These soil types are depicted in Figure 1–10. No hydrologic group A soils exist in the project area. The hydrologic group B soils are mainly located along streams. Group B has the highest infiltration rates and the lowest runoff potential, while group D has the lowest infiltration rates and the highest runoff potential. The unclassified areas mainly consist of rock outcrops. The shallow and exposed rock outcrops and shallow soils in areas with steep slopes results in high runoff and flow accumulation in the area. These data are based on the Soil Survey Geographic Database (SSURGO).

1.2.4 Elevation and Slope

Elevations range from approximately 7,720 feet to 9,037 feet and are shown in Figure 1–11. The lowest elevations are found in the southeast portion of the project area. The highest elevations are found in the northwest portion of the project area. Generally, the drainage flows from northwest to southeast. The average slope for the project area is approximately 15 percent.

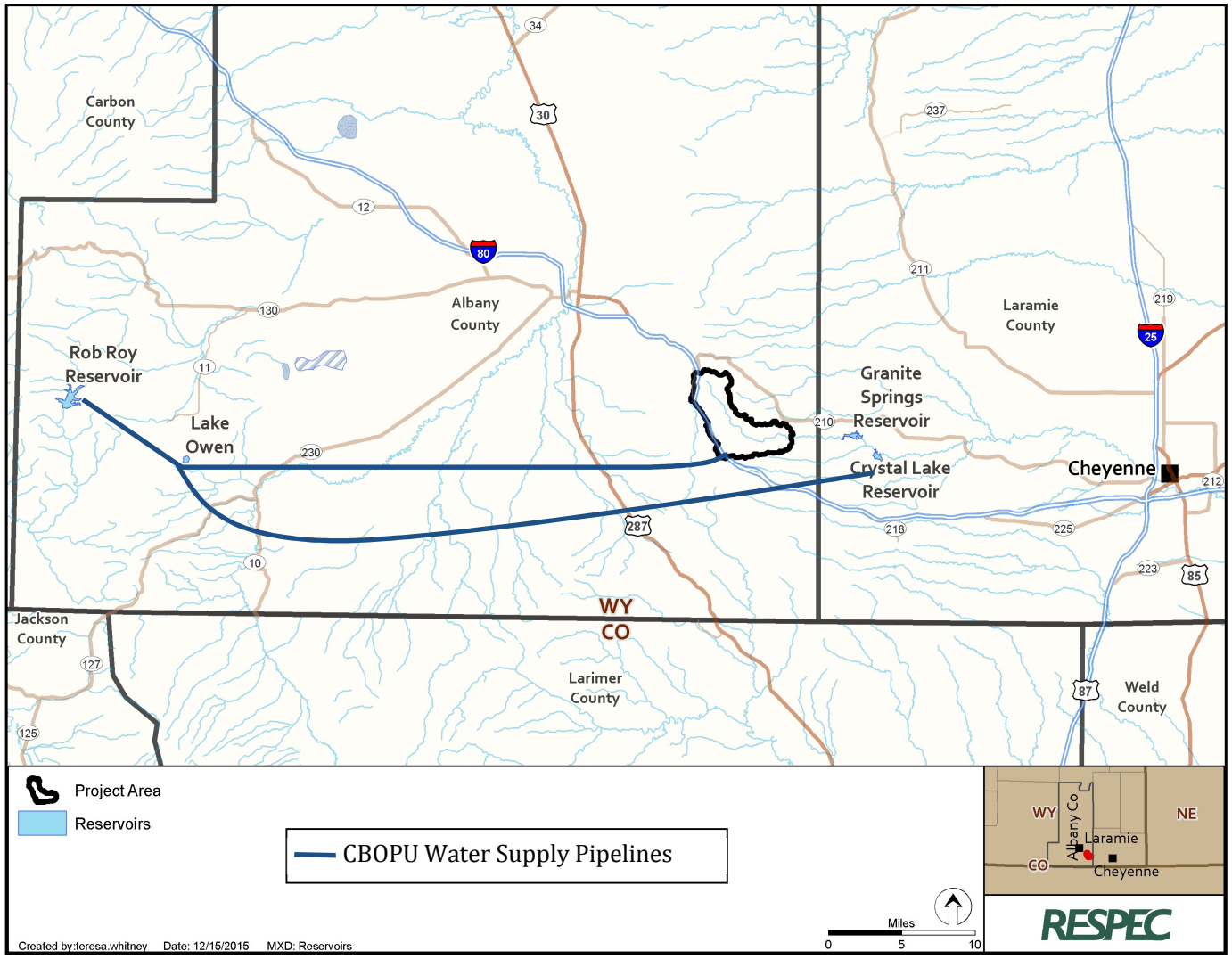


Figure 1-7. Schematic of Pipelines for Municipal Water for the City of Cheyenne.

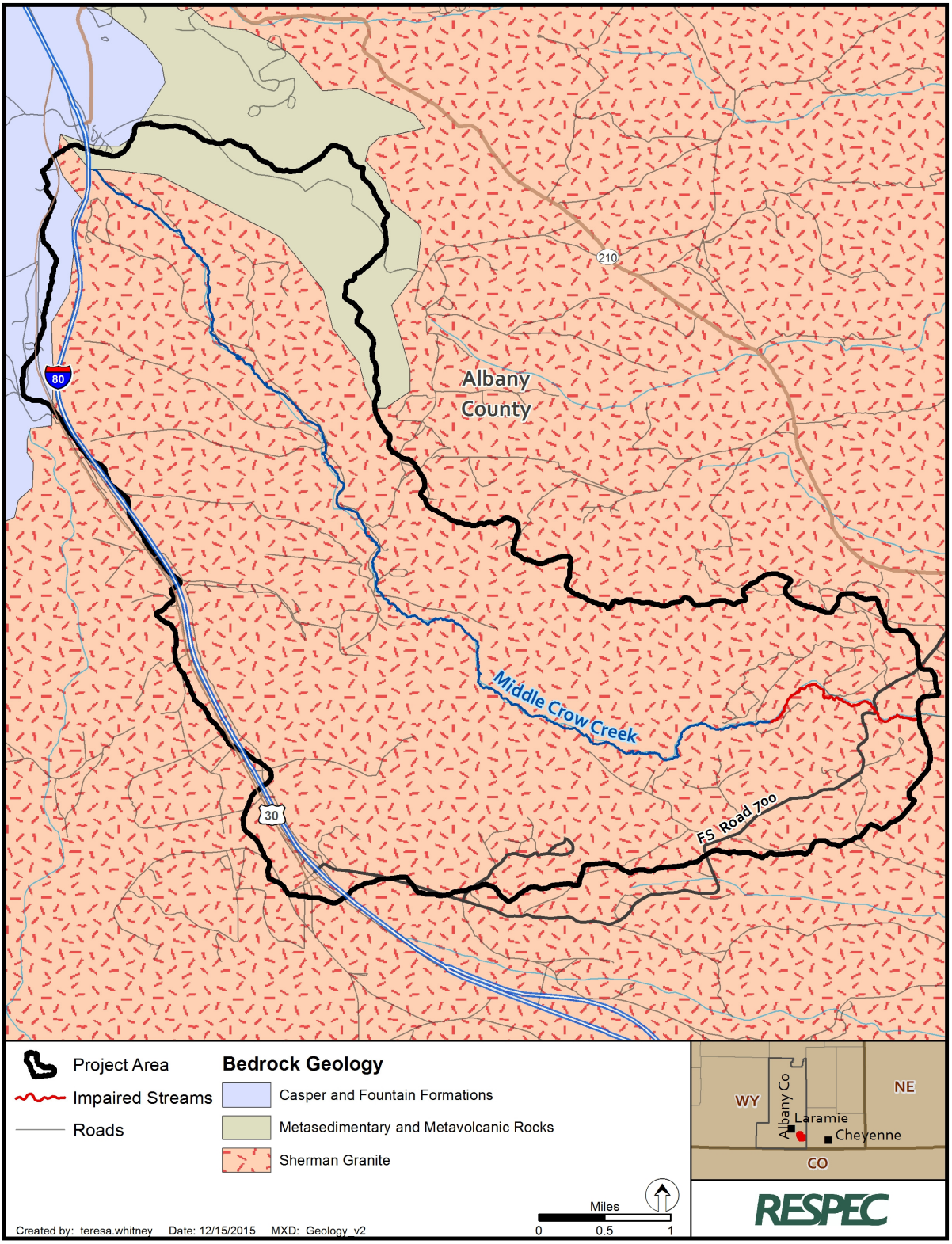


Figure 1-8. Bedrock Geology.

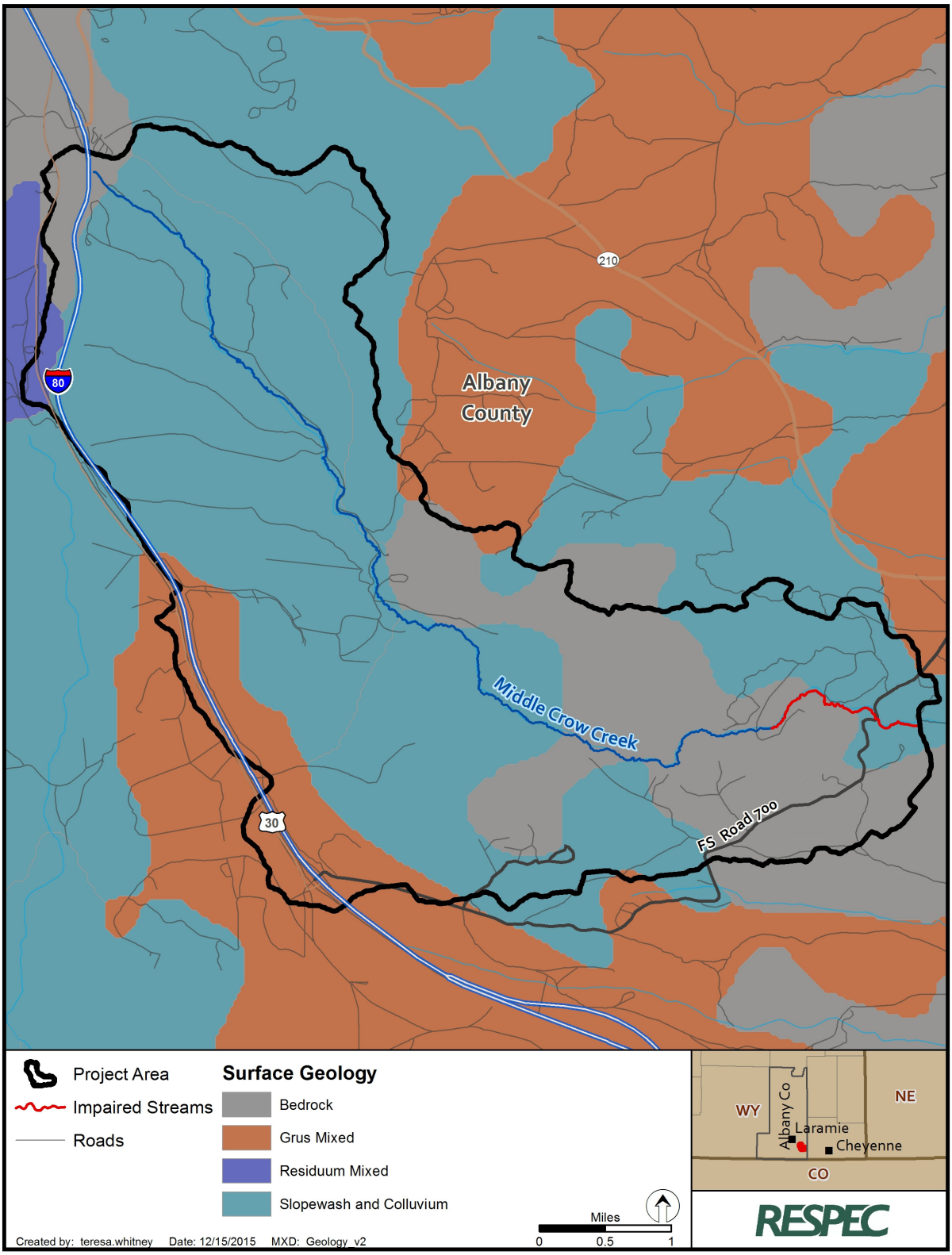


Figure 1-9. Surface Geology.

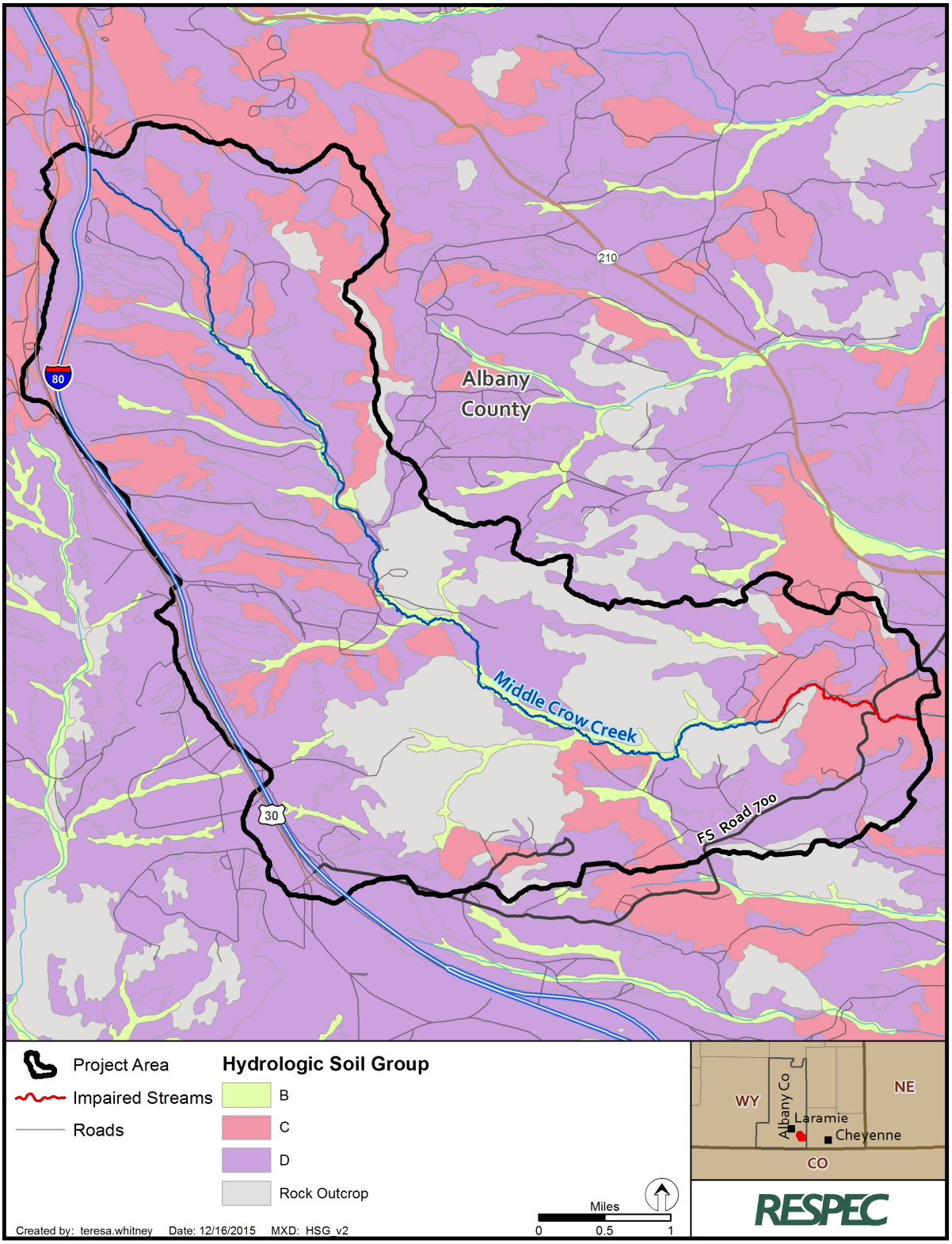


Figure 1-10. Hydrologic Soil Groups.

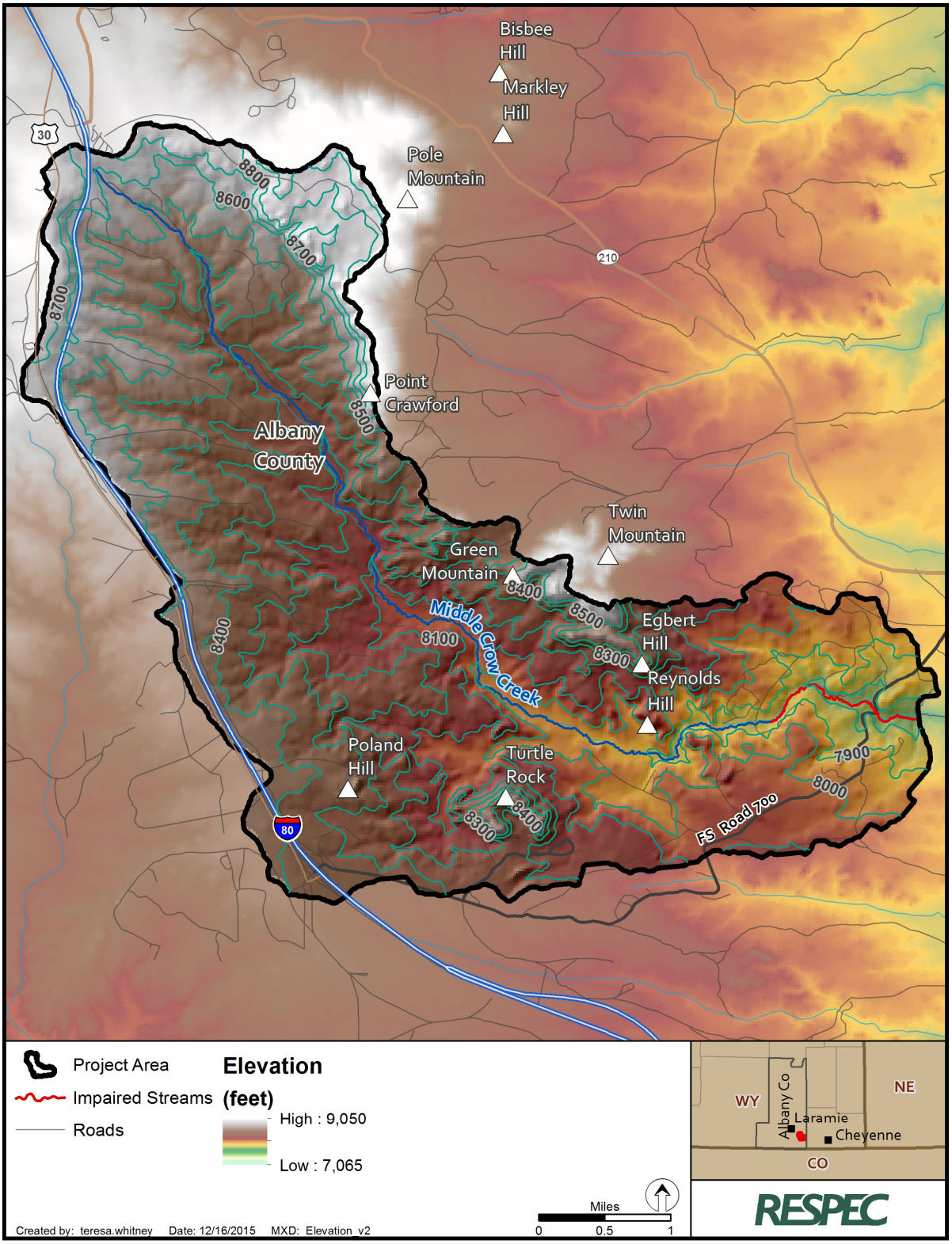


Figure 1-11. Elevations.

1.2.5 Recreational Use

The watershed is heavily used for recreational purposes. People visit the watershed for rock climbing, hiking, off-highway vehicle use, camping, fishing, and hunting. One U.S. Forest Service campground is located in the watershed. Dispersed camping, including both tent and recreational vehicle camping, is also an attraction. According to the USFS, approximately 50 campsites were counted in the Middle Fork Crow Creek Watershed in 1998 [Sanderson, 2015]. Over 60 miles of forest service roads (shown in Figure 1-1) allow campers and recreators access to nearly every area in the project area. Because of the easy access to the entire watershed, recreation has the potential to cause increased erosion and runoff. In particular, off-highway vehicle use results in creating new trails and roads and vegetation destruction [Eccleston et. al., 2004]. A Pole Mountain Travel Management project is in progress to provide diverse motorized and nonmotorized recreation opportunities; provide adequate access to manage natural resources, recreation, and permitted uses on the forest; and minimize user conflicts and impacts to the environment [USDA, 2015].

1.2.6 Grazing

The primary two grazing allotments in the project area are Green Mountain and Lodgepole. The Green Mountain allotment is subdivided into seven pastures, and the Lodgepole allotment is subdivided into three pastures. The Green Mountain allotment is managed under a deferred-rotation grazing system where only one pasture is grazed at any given time to allow vegetation to recover. The first pasture grazed during any year is the last to be grazed during the following year because of the stress from the first grazing. In recent years, the Lodgepole allotment has been using a rest-rotation grazing system, in which two pastures are grazing simultaneously while the third pasture is completely rested with no livestock use during that season. The rested pasture is rotated between the three pastures, which allows a different pasture to rest every year. Within the Middle Fork Crow Creek, the utilization target is 40–50 percent of each year's forage production, which is the equivalent to a stubble height of 4 to 6 inches for sedge [Eccleston et. al., 2004]. Grazing allotments are illustrated in Figure 1-12.

1.3 DISCHARGE AND WATER QUALITY CONDITIONS

All available discharge, *E. coli*, and fecal coliform data throughout the watershed were used for this project. Data locations are illustrated in Figure 1-13. A summary of the discharge and water quality conditions are included in the following sections. Water quality data (both *E. coli* and fecal coliform) were provided electronically to the WDEQ and can be obtained upon request.

1.3.1 Discharge

Continuous stream discharge data were available at two locations in the project area. The Experimental Program to Simulate Competitive Research (EPSCoR) collected discharge within the project area and the city of Cheyenne Board of Public Utilities (CBOPU) collected data at the inlet to Granite Springs Reservoir downstream of the impaired segment and project area. EPSCoR data were available from 2009 (1.5 months), 2010 (12 months), 2011 (12 months), 2012 (9.5 months), and 2013 (1.5 months). CBOPU data were available from mid-2002 through 2014. The average daily flow at the EPSCoR site was approximately 5 cfs, with average daily flows as low as 0 cfs and as high as 30 cfs. The average daily flow at the CBOPU site is approximately 6 cfs, with flows as low as 0 cfs and as high as 71 cfs. The CBOPU dataset

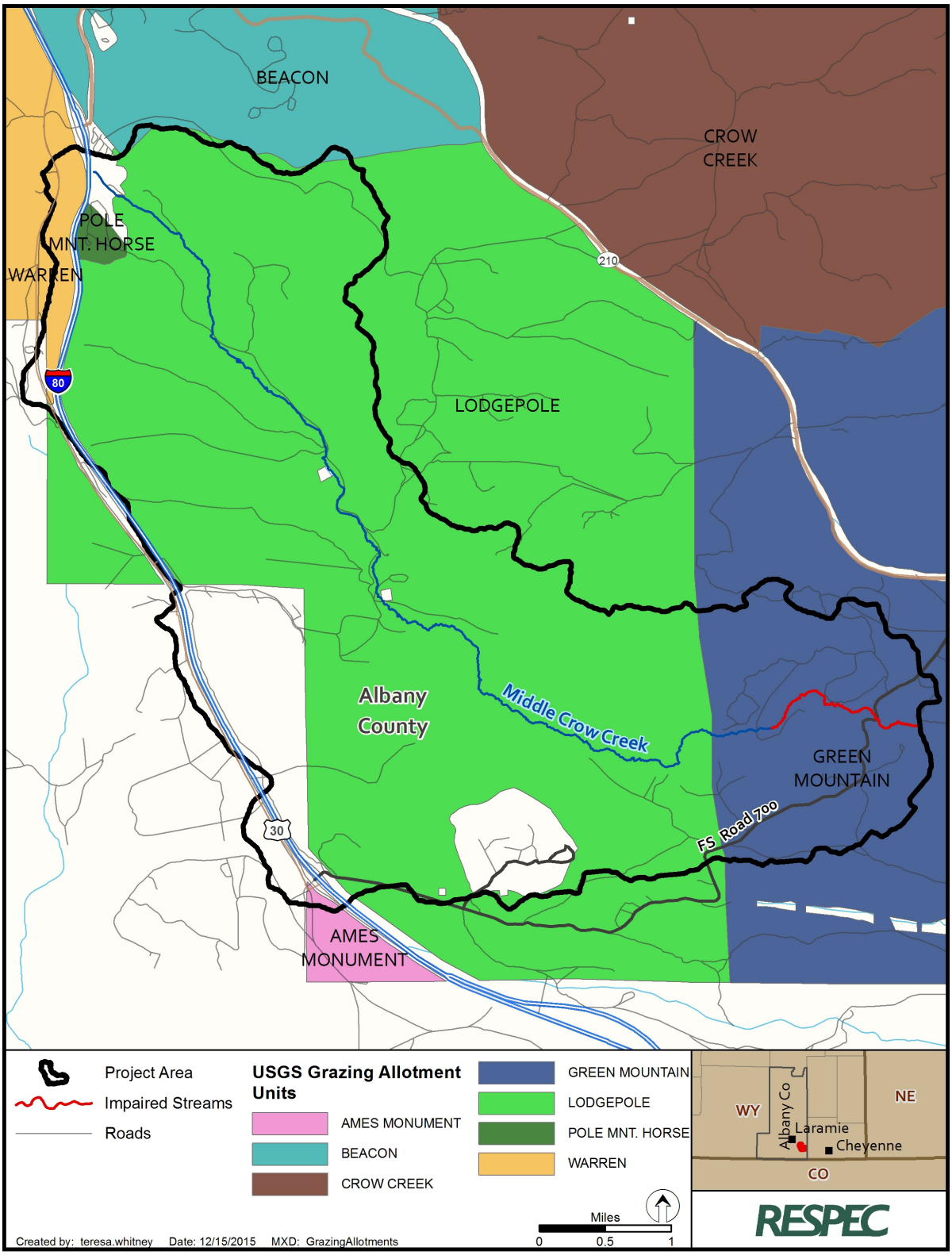


Figure 1-12. Grazing Allotments.

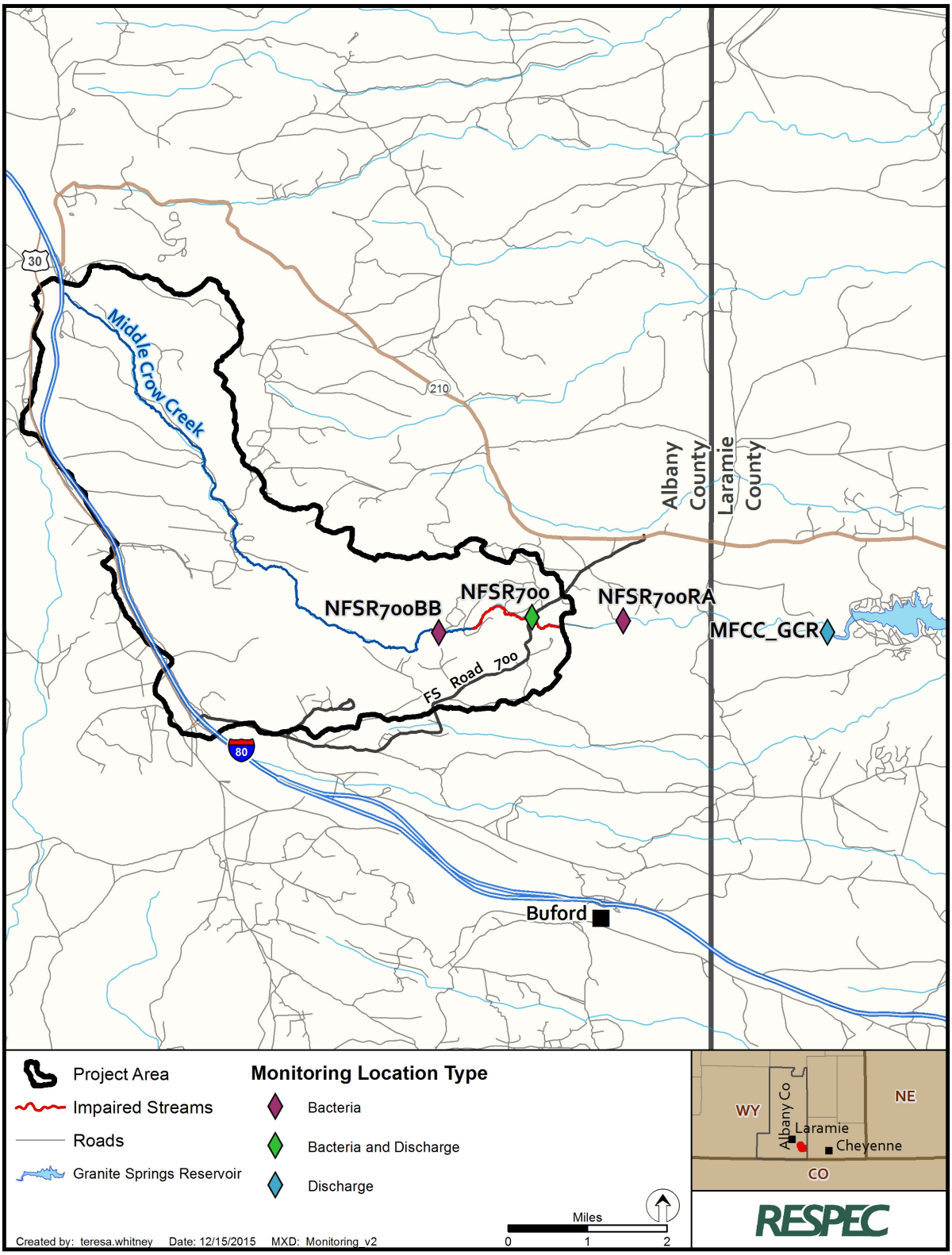


Figure 1-13. Discharge and Water Quality Monitoring Stations.

had data with a maximum of approximately 105 cfs. However, the CBOPU noted that a value was likely erroneous if it was uncharacteristically high in the winter months. Ice jams can skew flow measurements; once they pass flow measurements, they can become reliable again. Many discharge values above 71 cfs occurred during December, January, February, and March. These discharge values did not generally align with a significant precipitation event or a high-temperature event and were, therefore, not included in the statistics presented in Table 1-1. Similarly, 1 week in July had discharges of 105 cfs with no significant precipitation event and was excluded from the statistics in Table 1-1. The discharge data from the CBOPU pipeline into the watershed were also available, and the city of Cheyenne recommended reducing the values by 2 cfs [Chapman, 2015] to account for the 2 cfs transferred into North Bamford Creek and South Bamford Creek in the South Fork Crow Creek Watershed [Eccleston et al., 2004]. Figure 1-14 shows flows in the project area, which were typically highest in Middle Fork Crow Creek during the late spring and early summer months and lowest during the late summer and early fall months. The greatest median flow for Middle Fork Crow Creek occurred in May (12 cfs), and the smallest median flow (1 cfs) occurred in August and September. Discharge data were provided electronically to the WDEQ and can be obtained on request.

Table 1-1. Statistical Summary of Stream and River Daily Average Discharge Data Available During Modeling Period

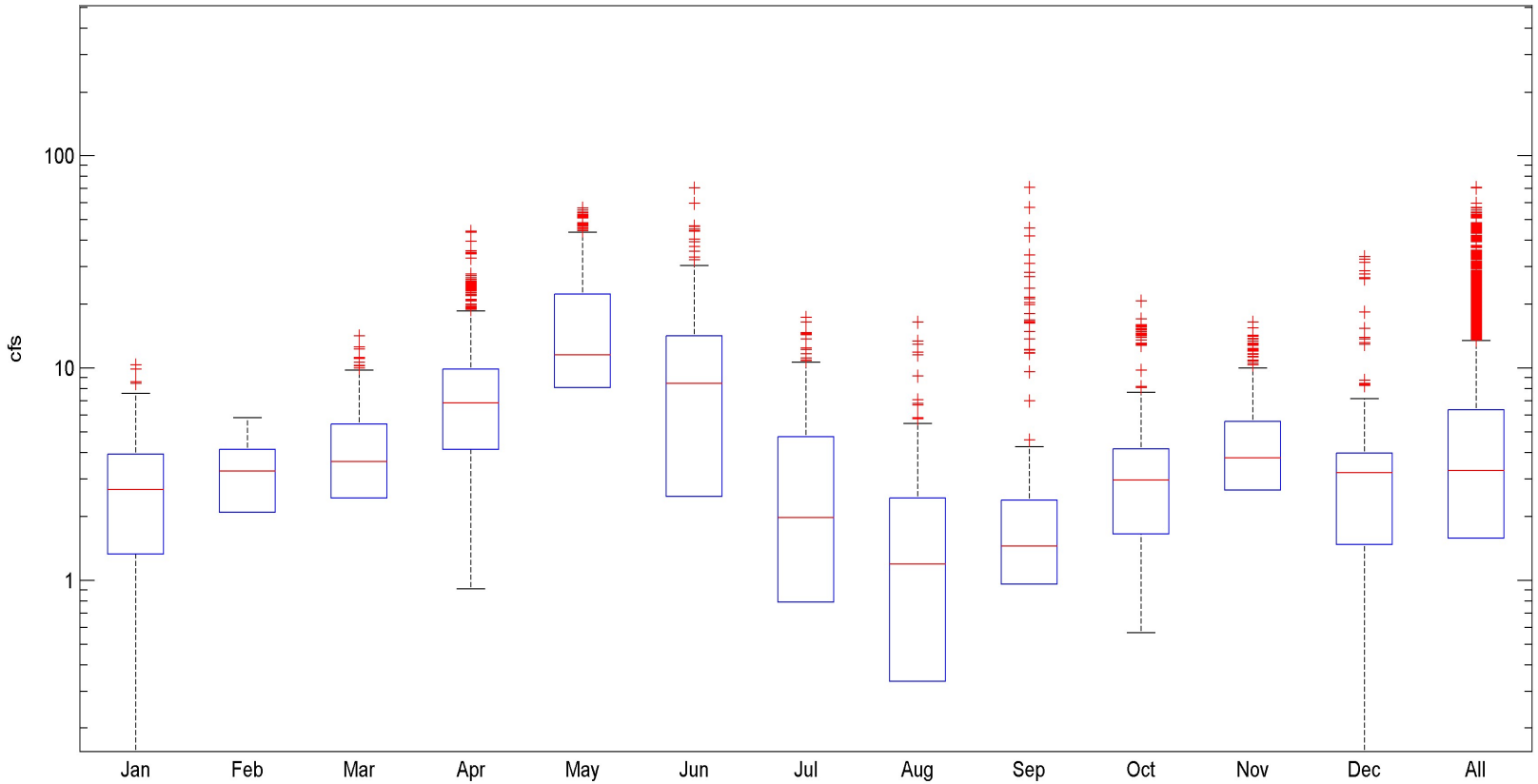
Site I.D.	NFSR700	MFCC_GCR
Site Description	MFCC at National Forest Service Road 700	MFCC Above Granite Springs Reservoir
Years of Availability	2009–2013	2002–2014
Number of Days	1,112	3,856
Minimum (cfs)	0.0	0.0
25th Percentile (cfs)	2.4	1.5
Median (cfs)	3.5	3.4
Average (cfs)	4.7	6.2
75th Percentile (cfs)	5.9	7.0
Maximum (cfs)	29.8	70.9

MFCC = Middle Fork Crow Creek

1.3.2 Water Quality

Laramie County Conservation District and WDEQ collected *E. coli* data within the impaired segment (NFSR700) from 2003 through 2014 [2007]. A summary of available *E. coli* data is presented in Table 1-2. One *E. coli* sample collected downstream of the impaired segment (NFSR700RA) in 2005 had a concentration of 38.8 org/100 mL and is not included in Table 1-2.

Laramie County Conservation District and the WDEQ also collected fecal coliform data within NFSR700. This data was collected both upstream (NFSR700BB) and downstream (NFSR700RA) of the impaired



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	All
n	247	199	287	360	372	360	364	372	360	372	359	296	3948
Min	0	0	0	1	0	0	0	0	0	1	0	0	0
Max	10	6	14	44	56	70	17	16	71	21	16	33	71
q1	1	2	2	4	8	2	1	0	1	2	3	1	2
Median	3	3	4	7	12	8	2	1	1	3	4	3	3
q3	4	4	5	10	22	14	5	2	2	4	6	4	6
Mean	3	3	4	9	16	10	3	2	3	4	5	4	6

Figure 1-14. Monthly Boxplot of Flow in Middle Fork Crow Creek Above Granite Springs Reservoir 2003–2014.

segment from 2003 through 2006. Four samples collected slightly upstream and downstream of a beaver dam at NFSR700 (NFSR700a and NFSR700b) were included in the NFSR700 statistics. A summary of available fecal coliform data is presented in Table 1-3.

Table 1-2. Summer Recreation Season *E. coli* Samples Available, Not Including Replicates

Site I.D.	NFSR700
Site Description	MFCC at National Forest Service Road 700
Years of Availability	2003–2014
Number of Samples	195
Minimum	<1
25th Percentile	57.5
Median	116
Average	270.9
75th Percentile	325.5
Maximum	1,733

Table 1-3. Summer Recreation Season Fecal Coliform Samples, Not Including Replicates

Site I.D.	NFSR700BB	NFSR700	NFSR700RA
Years of Availability	2004	2003–2006	2004
Number of Samples	5	67	6
Minimum	<4	<1	<4
25th Percentile	5	5	5.5
Median	25	20	12.5
Average	67.8	66.4	14.7.3
75th Percentile	115	55.5	18.8
Maximum	190	860	35

This report is written to include data through 2014. These data only included winter recreation season samples from the months of April and October. The average and maximum of these winter recreation season *E. coli* concentrations at NFSR700 were 12.2 org/100 mL and 25.6 org/100 mL, respectively. The average and maximum of all winter recreation season fecal coliform concentrations at NFSR700 were 9.9 org/100 mL and 50.0 org/100 mL, respectively. These April and October data suggest that concentrations throughout the winter recreation season remain well below the *E. coli* target of 630 org/100 mL.

A relationship was developed between all available paired fecal coliform and *E. coli* data. In the project area, 72 sets of concurrent *E. coli* and fecal coliform samples (71 sets from NFSR700 and one from NFSR700Ra) exist. The relationship was used to convert fecal coliform to an equivalent *E. coli* concentration by using linear regression. The regression had a coefficient of determination (R^2) of 0.91 and is shown in Equation 1-1 and Figure 1–15. *E. coli* concentrations were generally slightly higher than fecal coliform concentrations for paired samples. The inherent variability of bacteria or different methods being used to quantify these bacteria may have caused these higher concentrations. Fecal coliform concentrations are determined by a direct count by using a membrane filtration technique; *E. coli* concentrations are quantified using a multiple-well chromogenic substrate technique to achieve a statistical value. Both are valid, sensitive techniques [Larson, 2011]. The fecal coliform data were not used directly used to calculate the TMDL, which is written for *E. coli*. However, the translated fecal coliform data were used to calibrate an HSPF model application (discussed in Section 2.2.1). A set of annual boxplots was created by using both the actual *E. coli* samples and the translated *E. coli* samples. The plot in Figure 1-16 shows a general increasing trend.

$$C_E = 1.35 \times C_F + 4.2085 \tag{1-1}$$

where:

C_E = *E. coli* concentration

C_F = fecal coliform concentration.

E. coli data collected from May 1 through September 30 (summer recreation season) were used to calculate geometric means for computing the percent exceedance of the summer recreation season *E. coli* target of 126 org/100 mL. At NFSR700, approximately 74 percent of the 38 geometric means were above the 126 org/100 mL target, which is shown in Table 1–4.

The highest average and median bacteria concentrations in the project area occur in the spring and summer months, as depicted in Figure 1–17. The highest median bacteria concentration occur in June (195 org/100 mL), and the lowest occur in April (2 org/100 mL). Higher flows and higher bacteria concentrations occur during the late spring to early summer months, and by, extension, bacteria loads are also highest during this time period. The highest average and median bacteria concentrations in the project area occur in the spring and summer months. The highest median bacteria concentration occur in June (195 org/100 mL), and the lowest occur in April (2 org/100 mL). Higher flows and higher bacteria concentrations occur during the late spring to early summer months, and by extension, bacteria loads are also highest during this time period.

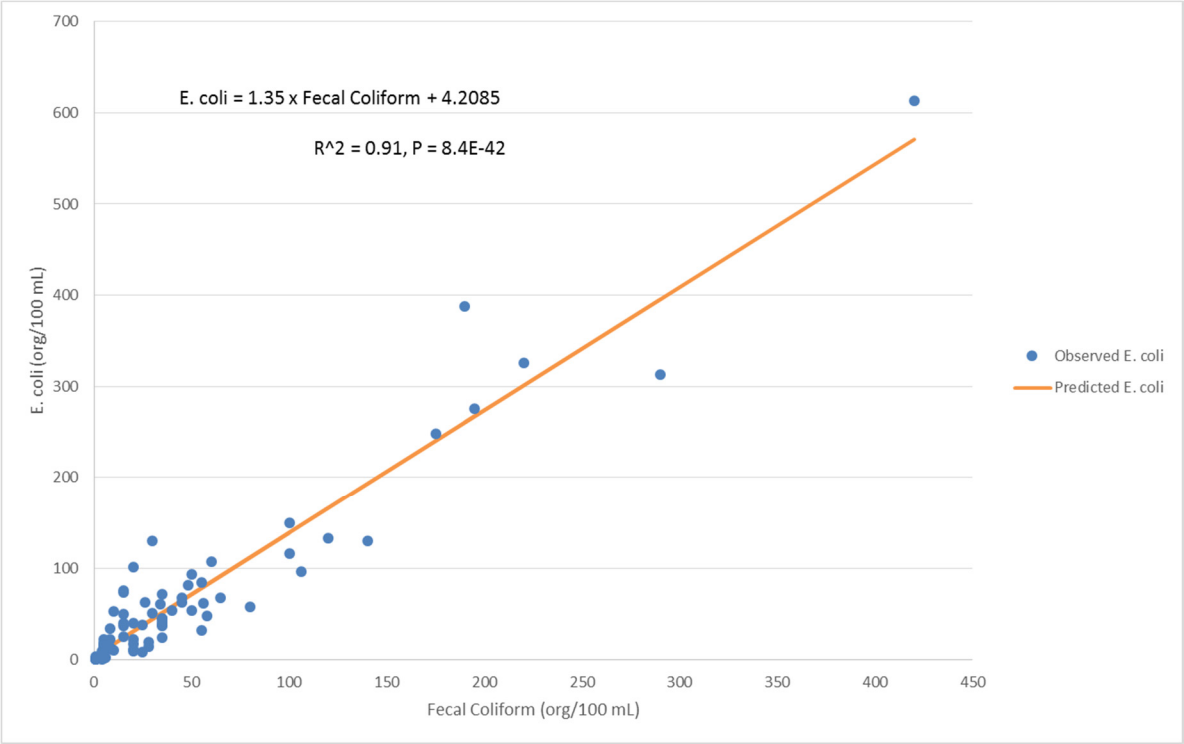


Figure 1-15. Regression Analysis Relationship Between All Available Paired Fecal Coliform and *E. coli* Samples.

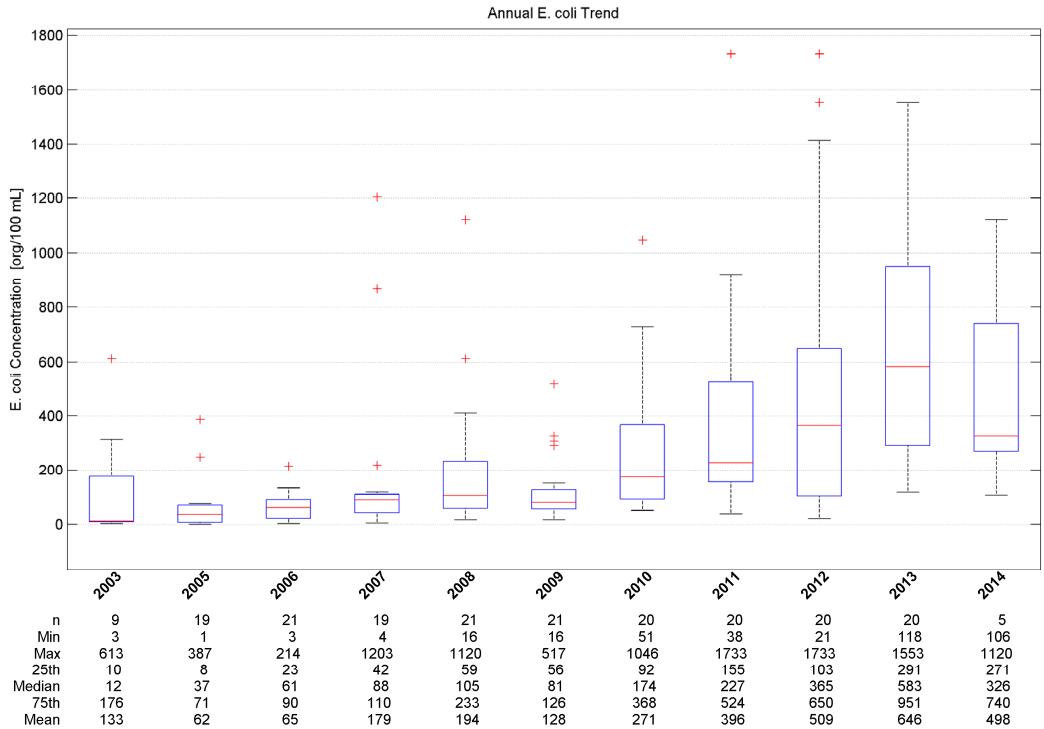


Figure 1-16. Time-Series Plot of *E. coli* Data and Translated Fecal Coliform Data.

Table 1-4. Summer Recreation Season *E. coli* 60-Day Geometric Mean Summary (Replicates Not Used)

Site I.D.	NFSR700
Years of Availability	2006–2013
Number of Geometric Means[(a)]	55
Minimum	44.4
25th Percentile	116.9
Median	204.8
Average	277.1
75th Percentile	436.0
Maximum	869.6
Percent Exceedance	72.7

(a) Single samples were averaged if more than one occurred during a 10-day period before a 60-day geometric mean calculation.

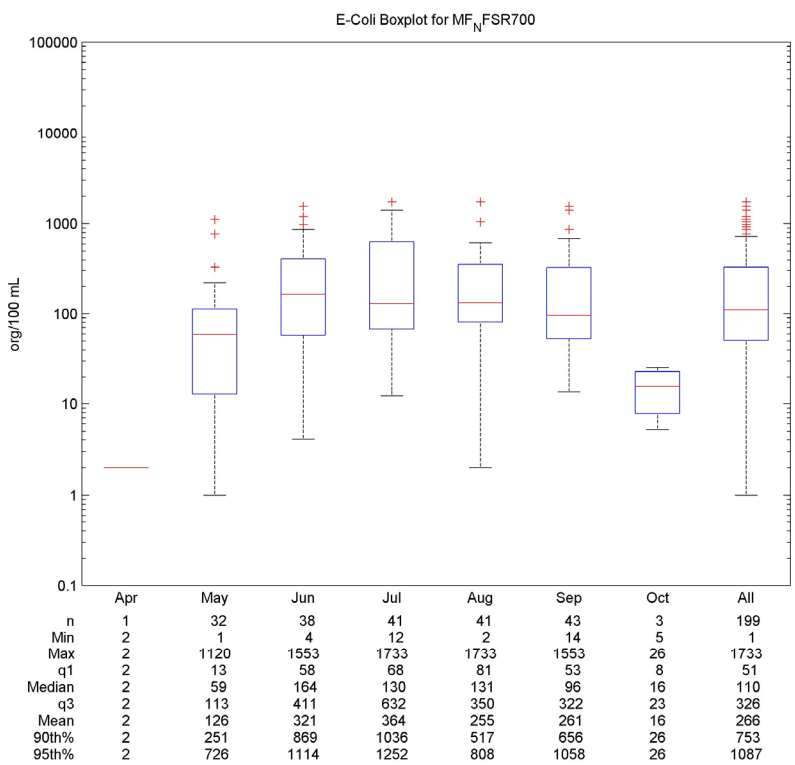


Figure 1-17. Boxplot of Monthly *E. coli* Concentrations From All Available *E. coli* Data (No Replicates).

2.0 SOURCE ASSESSMENT

This chapter describes the bacteria sources in the project area, which mainly include nonpoint sources. No permitted wastewater treatment facilities (WWTFs) or concentrated animal feeding operations (CAFOs) are located within the project area. Nonpoint sources are sources that can be transported through watershed runoff. The sources are described first, and then the methods and results of the source load assessment are presented.

2.1 BACTERIA SOURCE INVENTORY

Possible point and nonpoint sources within the project area are summarized below.

2.1.1 Point Sources

No permitted WWTFs or CAFOs are located in the project area [Coleman, 2015].

2.1.2 Nonpoint Sources

Based on a review of available land-use information and communication with state and local authorities, nonpoint sources of bacteria within the project area may include livestock, wildlife, human, and pet sources. Manure from livestock is a potential source of bacteria to the stream. Livestock contribute bacteria loads directly by defecating in the stream and indirectly by defecating in grazing allotments where bacteria can be washed off during precipitation events or snow melt. Livestock (cattle and sheep) are grazed in the USFS portion of the project area during summer and early fall months. Wildlife, including waterfowl and large game species, also contribute bacteria loads directly by defecating while wading or swimming in the stream and indirectly by defecating on lands that produce watershed runoff during precipitation events. Because of the close proximity to the cities of Cheyenne, Wyoming, and Laramie, Wyoming, this area is heavily used for camping and outdoor recreation. Human bacteria sources in the project area would likely be related to dispersed campers who improperly dispose of waste. Similarly, pet waste from the pets of dispersed campers is a potential source of bacteria. Approximately ten septic systems and two vault toilets exist in the project area. If not properly maintained, septic systems and vault toilets are a potential source of human bacteria to the stream. More information about recreational use and grazing practices in the project is included in Section 1.2, and details about estimation of nonpoint sources for the HSPF model application are included in Section 2.2.

2.2 SOURCE LOAD ASSESSMENT

An HSPF model application was developed for the project area to determine the contribution of *E. coli* bacteria from identified sources and to evaluate different scenarios of implementing BMPs to control these sources. The model application can be used to predict the range of flows that have historically occurred in the modeled area, to quantify the load contributions from a variety of sources in a watershed, and to help quantify source contributions when paired flow and concentration data are limited.

HSPF is a comprehensive watershed model of hydrology and water quality that includes modeling land surface and subsurface hydrologic and water quality processes, which are linked and closely integrated with corresponding stream processes. The framework can be used to determine the critical environmental conditions (e.g., certain flows or seasons) for the impaired segments by providing continuous flow and load predictions at different points in the system. HSPF simulates the fate and transport of bacteria.

The bacteria accumulation and storage rates of nonpoint sources were calculated by using the Bacteria Source Load Calculator (BSLC). The sum of the source estimates from the BSLC (including accumulation, storage rates, and direct defecation) were then entered into HSPF, and the bacteria buildup and washoff were simulated by using HSPF. The following sections provide more detail on the source assessment approach and provide the quantitative results of the source load assessment.

2.2.1 Model Methods

The primary components of developing an HSPF model application include the following:

- Gathering and developing time-series data
- Characterizing and segmenting the watershed
- Estimating bacteria loads and modeling bacteria accumulation and storage rates
- Calibrating and validating the model.

2.2.1.1 *Gathering and Developing Time-Series Data*

Data requirements for developing and calibrating an HSPF model application are both spatially and temporally extensive. The modeling period was from 2004 through 2014. Time-series data used in developing the model application included the following:

- Meteorological data
- Stream flow and water quality data
- CBOPU water supply pipeline data.

Precipitation, potential evapotranspiration, air temperature, wind speed, solar radiation, dew-point temperature, and cloud cover data are needed for HSPF to simulate hydrology (including snow processes). Precipitation and air temperature used were from SNOTEL, while the remainder of the meteorological data were from the Laramie airport. Missing data were filled with data from the Cheyenne airport.

2.2.1.2 *Segmenting and Characterizing the Watershed*

The project area was delineated into 13 subwatersheds to capture hydrologic and water quality variability. Subwatersheds are shown in Figure 2-1. The watershed was then segmented into individual land and channel pieces that are assumed to demonstrate relatively homogeneous hydrologic, hydraulic, and water quality characteristics. This segmentation provides the basis for assigning similar or identical input and/or parameter values or functions to all portions of a land area or channel length contained in

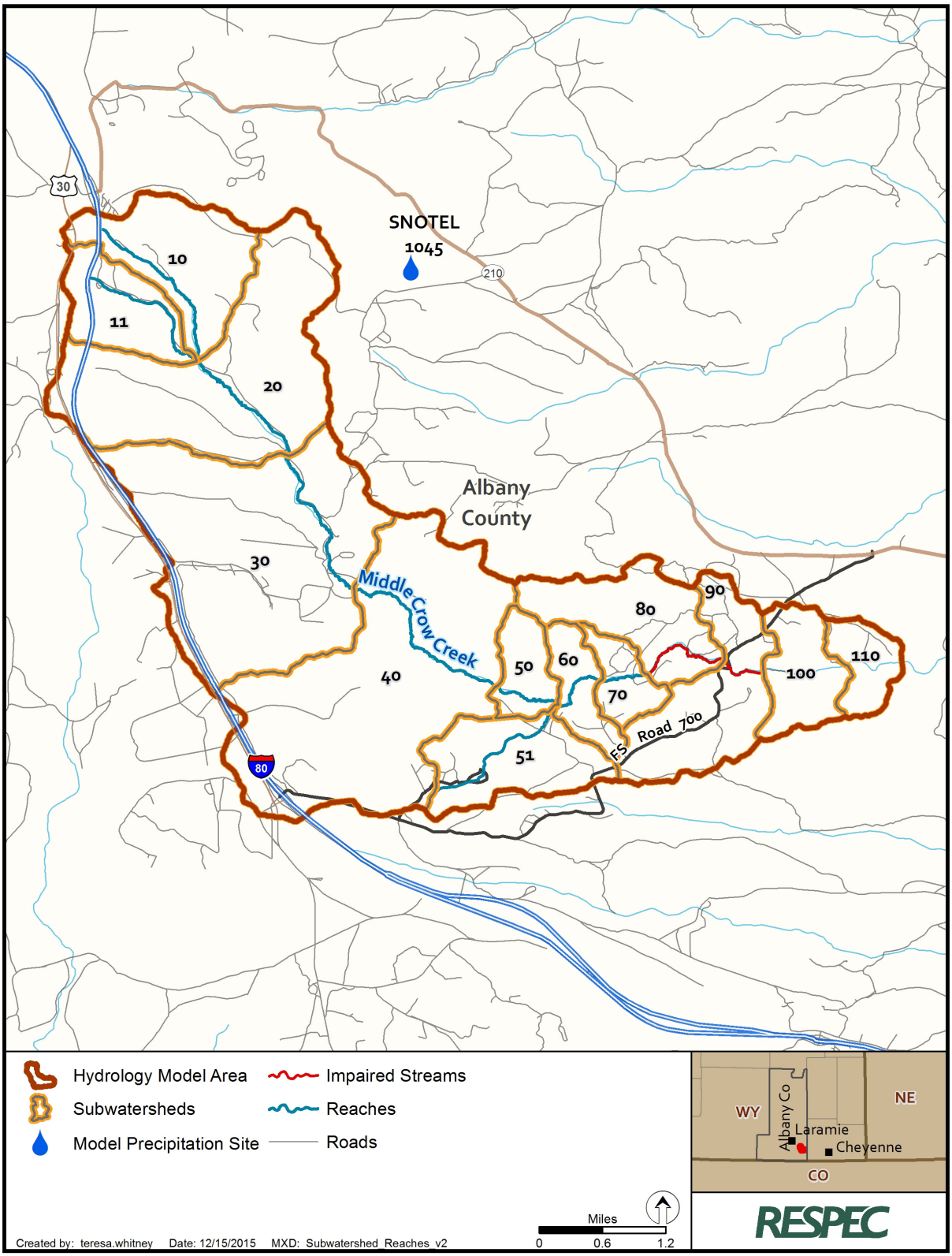


Figure 2-1. Subwatersheds and Reaches.

a model segment. The individual land and channel segments are linked together to represent the entire project area. Metrics for each reach are included in Table 2-1.

Table 2-1. Subwatershed Metrics

Reach I.D.	Length (mi)	Slope (percent)	Area (acres)
10	1.8	3.1	891
11	1.5	2.5	552
20	1.5	1.6	2,077
30	1.9	1.6	2,683
40	2.1	1.2	2,935
50	0.7	1.3	303
51	1.6	4.2	749
60	0.6	1.8	315
70	0.5	1.5	265
80	1.0	1.6	765
90	0.5	1.3	954
100	0.9	1.6	478
110	0.6	1.4	297
120	2.9	2.1	3,297

The land segmentation was defined by land cover. Land use and land cover affect the hydrologic and water quality response of a watershed through their impact on infiltration, surface runoff, and water losses from evapotranspiration. The movement of water through the system is affected by land cover. Land use affects the rate of the accumulation of pollutants, such as bacteria, because certain land uses often support different pollutant sources.

Land cover categories (based on the NLCD) were combined into five groups with similar characteristics, as illustrated in Figure 2–2. The urban categories were divided into pervious and impervious areas based on an estimated percentage of effective impervious area (EIA). The term "effective" implies that the impervious region is directly connected to a local hydraulic conveyance system (e.g., open channel and river), and the resulting overland flow will not run onto pervious areas but will rather directly enter the reach network.

The channel segmentation considers river travel time, riverbed slope continuity, temporal and spatial cross section and morphologic changes or obstructions, the confluence of tributaries, impaired reaches, and locations of flow and bacteria calibration and verification gages. After the reach network was segmented, the hydraulic characteristics of each reach were computed, and the areas of the land cover

categories that drain to each reach were calculated. Reach hydraulics are specified by a reach function table (F-table), which is an expanded rating curve that contains the reach surface area, volume, and discharge as functions of depth. F-tables were developed for each reach segment by using channel cross-sectional data from the NFSR700 road crossing and relative drainage areas.

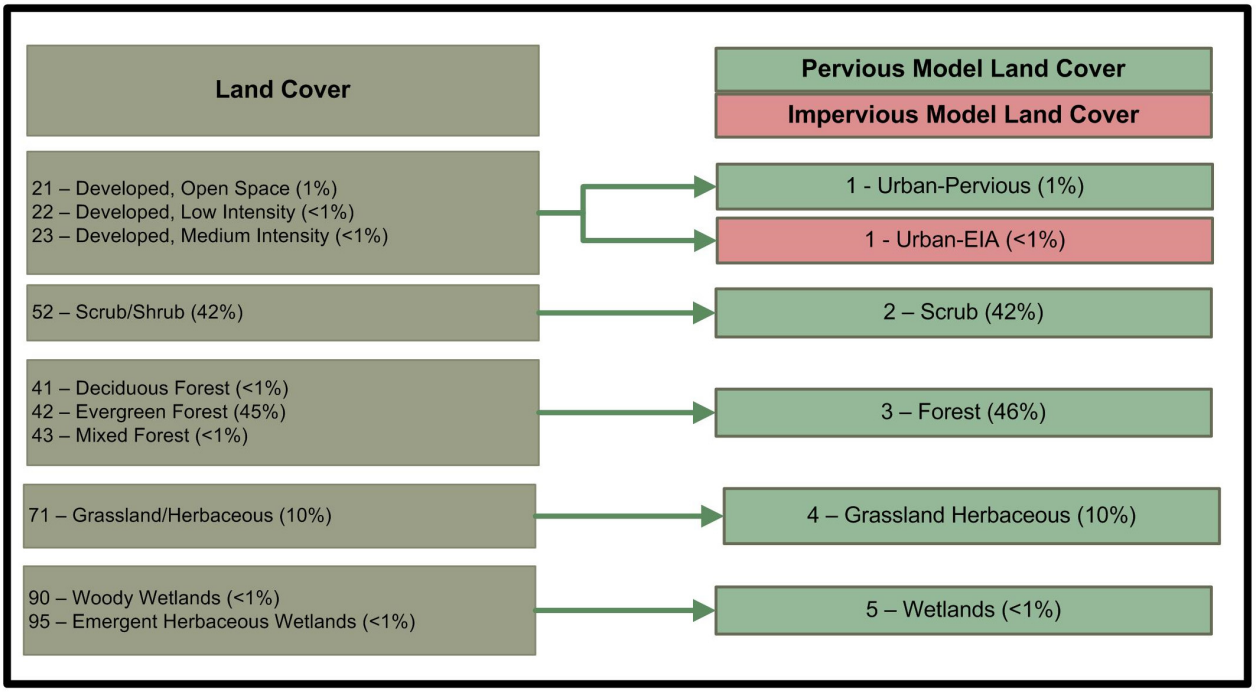


Figure 2-2. Model Land Cover Representation.

2.2.1.3 *Estimating Bacteria Loads and Modeling Bacteria Accumulation and Storage Rates*

The BSLC, developed by the Center for TMDL and Watershed Studies [2007], was used to estimate *E. coli* loads. The BSLC estimates bacteria accumulation and storage from nonpoint-source runoff, which consists of livestock, wildlife, and dispersed camper (human and pet). The BSLC also estimates direct stream defecation from livestock, wildlife, and failing septic systems within the riparian zone.

The BSLC outputs fecal coliform estimates. Note that the water quality targets and laboratory and model results were reported as org/100 mL, while BSLC estimates were in cfu/100 mL. These units are interchangeable. Fecal coliform data were translated to *E. coli* by using the regression data discussed in the Water Quality Section. These translated data were used during the HSPF calibration process. The distributions from the BSLC tool are the drivers of the bacteria portion of the model; when calibration occurs, instream concentrations are calibrated to observed *E. coli* data. The *E. coli* load estimates were then used in an HSPF model application to assess the fate and transport of *E. coli*.

Livestock population estimates for the BSLC in the project area were derived from the Lodgepole, Green Mountain, and Warren Allotment Rangeland Management Units Data (2004–2014) [Roaque, 2015]. Total allotment numbers were area weighted based on the percent of the allotment in the watershed. The livestock density estimates were combined with fecal coliform production estimates for each animal type

[Wagner and Moench, 2009] to determine the amount of fecal coliform produced per day per animal type in the project area. These estimates are shown in Table 2.2

Table 2-2. Project Area Livestock Estimates

Livestock Category	Estimated Population in Project Area	Fecal Coliform Produced per Animal (cfu/day)	Fecal Coliform Produced in Project Area (cfu/day)
Cattle (June through September)	586	8.55×10^9	5.01×10^{12}
Sheep and Lambs (June through September)	61	4.32×10^9	2.64×10^{11}
Chicken Layers	5	3.70×10^8	1.85×10^9
Horses	14	3.64×10^8	5.10×10^9

A Wyoming Game and Fish area expert determined the number of whitetail deer, mule deer, moose, and elk [Knox, 2015]. The number of antelope was estimated by using herd unit and animal observation data from Wyoming Game and Fish, and the estimated number was confirmed by the Wyoming Game and Fish area expert. Small game animal numbers were estimated by using suggested densities from the Center for TMDL and Watershed Studies [2007]. The Wyoming Game and Fish area expert confirmed that the estimates looked reasonable. Wildlife estimates are included in Table 2-3.

Table 2-3. Wildlife Estimates

Wildlife Category	Estimated Population in Project Area	Fecal Coliform Produced per Animal (cfu/day)	Fecal Coliform Produced in Watershed (cfu/day)
Raccoons	472	5.00×10^7	2.36×10^{10}
Mule Deer	225	1.68×10^9	3.78×10^{11}
Muskrats	116	2.50×10^7	2.90×10^9
Elk	100	7.64×10^9	7.64×10^{11}
Beavers	98	2.00×10^5	1.96×10^7
Whitetailed Deer	75	1.68×10^9	1.26×10^{11}
Wild Turkey	75	9.30×10^7	6.98×10^9
Antelope	72	1.41×10^9	1.02×10^{11}
Moose	8	1.27×10^{10}	1.02×10^{11}
Geese–Peak	5	8.00×10^8	4.00×10^9
Ducks–Peak	4	2.40×10^9	9.60×10^9
Ducks–Nesting	3	2.40×10^9	7.20×10^9
Geese–Nesting	3	8.00×10^8	2.40×10^9

The number of septic systems was estimated by using aerial imagery. All households in the project area were assumed to have a septic system. Using this assumption, the number of septic systems in the project

area was estimated to be approximately 10. The number of septic systems was converted to the number of individuals by using septic systems using an average household size (2.3 people per household) from the 2010 Census [U.S. Census Bureau, 2015]. A human fecal coliform production rate of 2.0×10^9 cfu/person/day (suggested by the BSLC) was used in the BSLC. Total households were then used to estimate the pet population. The BSLC suggests a default of one dog (which is assumed to equal two cats) per household, with a fecal coliform production rate of 4.5×10^8 cfu/pet/day.

Approximately 50 campsites were counted in the Middle Fork Crow Creek Watershed in 1998 [Sanderson, 2015]. One-third of the campsites were assumed to be used at any given time in June, July, and August, with approximately 2.25 individuals per campsite (2010 Census [U.S. Census Bureau, 2015] people per household). Therefore, approximately 38 dispersed campers are assumed to be in the watershed at any given time during June, July, and August. One-quarter of the individuals are assumed to be camping during the cooler months of May and September. Therefore, approximately 10 dispersed campers are assumed to be in the watershed at any given time during May and September. Because many dispersed campers bury or pack waste out, this number is conservative. Similarly, it is likely that the number of dispersed campers is higher on weekends and lower on week days; therefore, the estimations described above represent the average condition. Dispersed campers were represented by using a fecal production rate of 2.0×10^9 cfu/person/day (human rate recommended by BSLC). Fecal coliform estimates from anthropogenic sources are shown in Table 2-4.

Table 2-4. Project Area Anthropogenic Estimates

Category	Estimated Population in Project Area	Fecal Coliform Produced per Animal (cfu/day)	Fecal Coliform Produced in Project Area (cfu/day)
Residents	10	2.0×10^9	2.0×10^{10}
Resident Pets	4	4.5×10^8	1.8×10^9
Campers (June, July, August)	38	2.0×10^9	7.6×10^{10}
Campers (May, September)	10	2.0×10^9	2.0×10^{10}

2.2.1.4 *Calibrating and Validating the Model*

Model calibration involved hydrologic and water quality calibration by using observed flow and water quality data to compare to simulated results. Because water quality simulations depend highly on watershed hydrology, the hydrology calibration was completed first, followed by the bacteria calibration. All data from the stream discharge site above the Granite Reservoir were used for the calibration and validation. While the model was run from 2003 through 2014, the model was only calibrated using the years from 2004 through 2014. The initial year (2003) was simulated for the model to adjust to existing conditions. The 12-year simulation period included a range of dry and wet years. This range of precipitation improves the model calibration and validation and provides a model application that can simulate hydrology and water quality during a broad range of climatic conditions. Hydrologic calibration is an iterative process intended to match simulated flow to observed flow by methodically adjusting model parameters such as infiltration and evapotranspiration. Information on hydrology calibration parameters

are available in EPA Basins Technical Note 6: Estimating Hydrology and Hydraulic Parameters for HSPF [EPA, 2000]. HSPF hydrologic calibration is divided into the following four sequential phases of adjusting parameters to improve model performance:

- Annual runoff
- Seasonal or monthly runoff
- Low- and high-flow distribution
- Individual storm hydrographs.

By iteratively adjusting calibration parameters within accepted ranges, the simulation results are improved until an acceptable comparison of simulated results and measured data is achieved. The procedures and parameter adjustments involved in these phases are more completely described in Donigian et al. [1984] and Lumb et al. [1994].

The bacteria calibration begins with the bacteria accumulation that was determined using the BSLC. Bacteria was calibrated from 2008 through 2014, to represent the most current conditions seen in the watershed. Once the BSLC information is input into the model, the model is calibrated so that the observed instream concentrations match the simulated concentrations to the maximum extent possible. Several parameters can be adjusted to calibrate *E. coli* loads and concentrations. To calibrate under baseflow conditions, adjustments are typically made to parameters that represent continuous discharges that do not depend on transport via runoff mechanisms, (i.e., direct sources). Direct sources in the project area could include contributions from direct deposition from wildlife or livestock. Direct sources may also involve other mechanisms that are difficult to quantify explicitly, including illicit discharges and the resuspension of bacteria associated with sediment. To calibrate under watershed runoff conditions, parameters that relate to bacteria wash off from land surfaces are adjusted. Adjustments of the first-order decay rate for bacteria are also used to calibrate the instream concentrations. Note that because of adjustments during the bacteria calibration process, breakdown of bacteria loads by animal group is outside of the confidence of the model application.

2.2.2 Model Calibration Results

The hydrology calibration was evaluated by using a weight-of-evidence approach based on a variety of graphical comparisons and statistical tests. The performance criteria are described in more detail in Donigian [2002]. Graphical comparisons included monthly and average flow-volume comparisons, daily time-series data comparisons, and concentration-duration plots. Statistical tests included annual and monthly runoff errors, low-flow and high-flow distribution errors, and storm-volume and peak-flow errors.

The calibration parameters were adjusted to improve the model performance until the preferred performance criteria were met or there was no apparent improvement from parameter refinement. The graphical plots were visually evaluated to objectively assess the model performance, and the statistics were compared to objective criteria developed from 20 years of experience with HSPF applications. The correlation coefficient (r) and the coefficient of determination (r2) were compared with the criteria in Figure 2-3 to evaluate the performance of the daily, monthly, and annual flows. Daily, monthly, and annual hydrology calibration plots are shown in Figures 2-4, 2-5, and 2-6, respectively. These measures allow the

user to assess the quality of the overall model application performance in descriptive terms, which aids in deciding to accept or reject the model application. The developed performance criteria are explained in detail in Donigian [2002]. The flow time-series plots that compare observed and simulated data at the Granite Springs Reservoir gage show that the flow peaks and baseflow conditions are adequately represented (i.e., match up well) by the model application, as shown in Figure 2–3. The monthly R^2 for this gage was 0.88 and the daily r^2 for this gage was 0.81; both of which represent a very good hydrology calibration based on Figure 2-3.

Figure 2-3. General Calibration *R* and R^2 Targets for HSPF Applications.

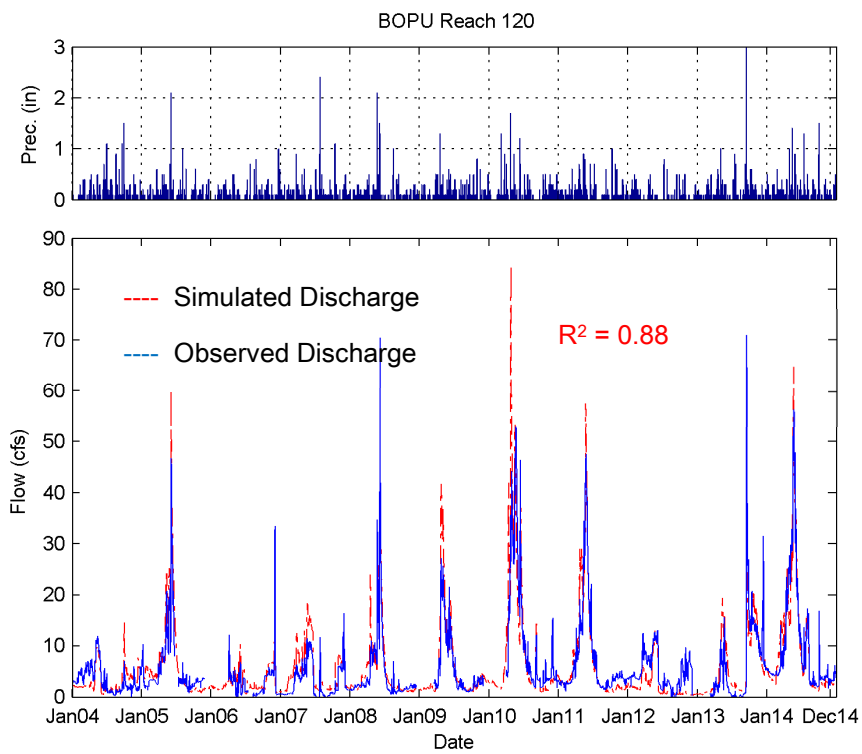


Figure 2-4. Simulated and Observed Discharge Above Granite Springs Reservoir.

The monthly average boxplot of simulated and observed *E. coli* concentrations in the impaired reach of the Middle Fork Crow Creek, shown in Figure 2-7, illustrates that the model is representing watershed conditions well. Similarly, concentration-duration curves that compare observed and simulated concentrations in the impaired segment show that the model is representative of the actual watershed conditions. Figure 2–8 shows the concentration-duration calibration curve from Middle Fork Crow Creek.

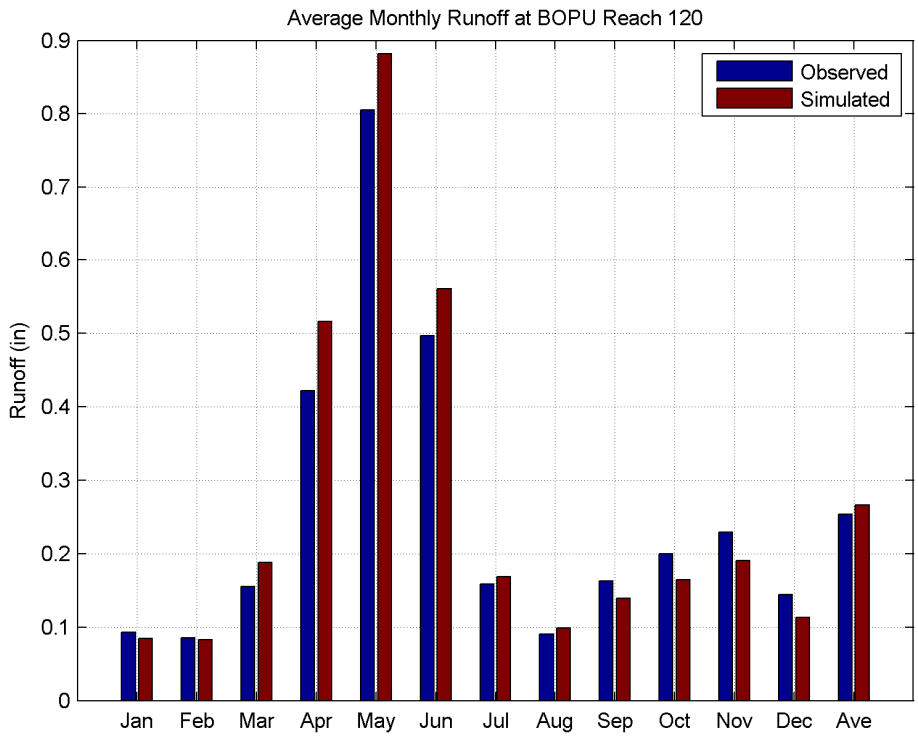


Figure 2-5. Simulated and Observed Monthly Runoff Above Granite Springs Reservoir.

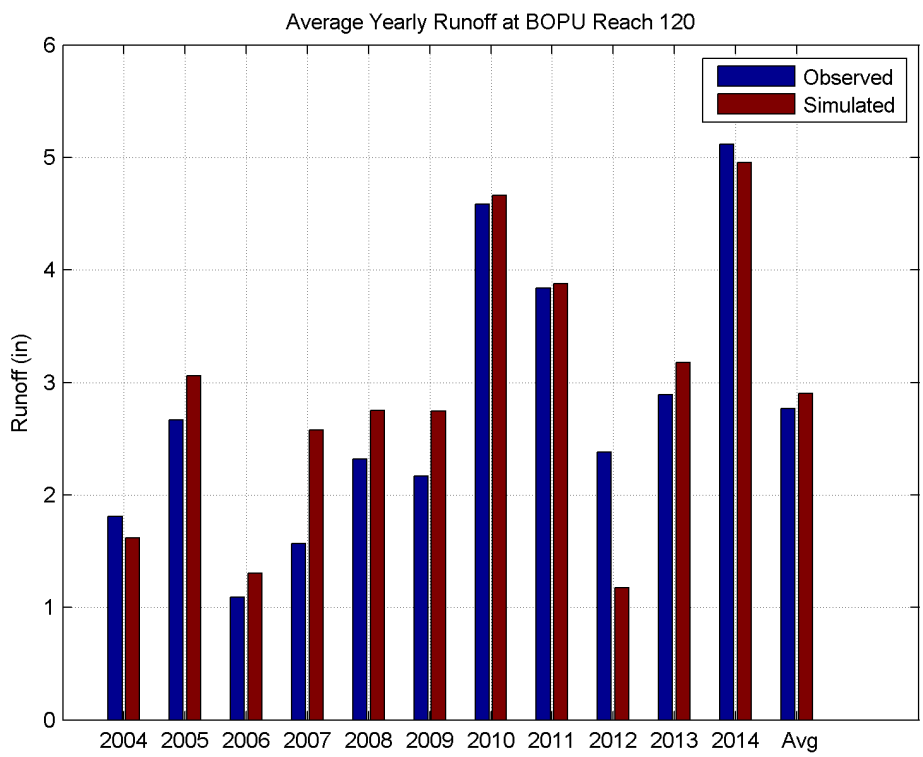


Figure 2-6. Simulated and Observed Average Annual Runoff Above Granite Springs Reservoir.

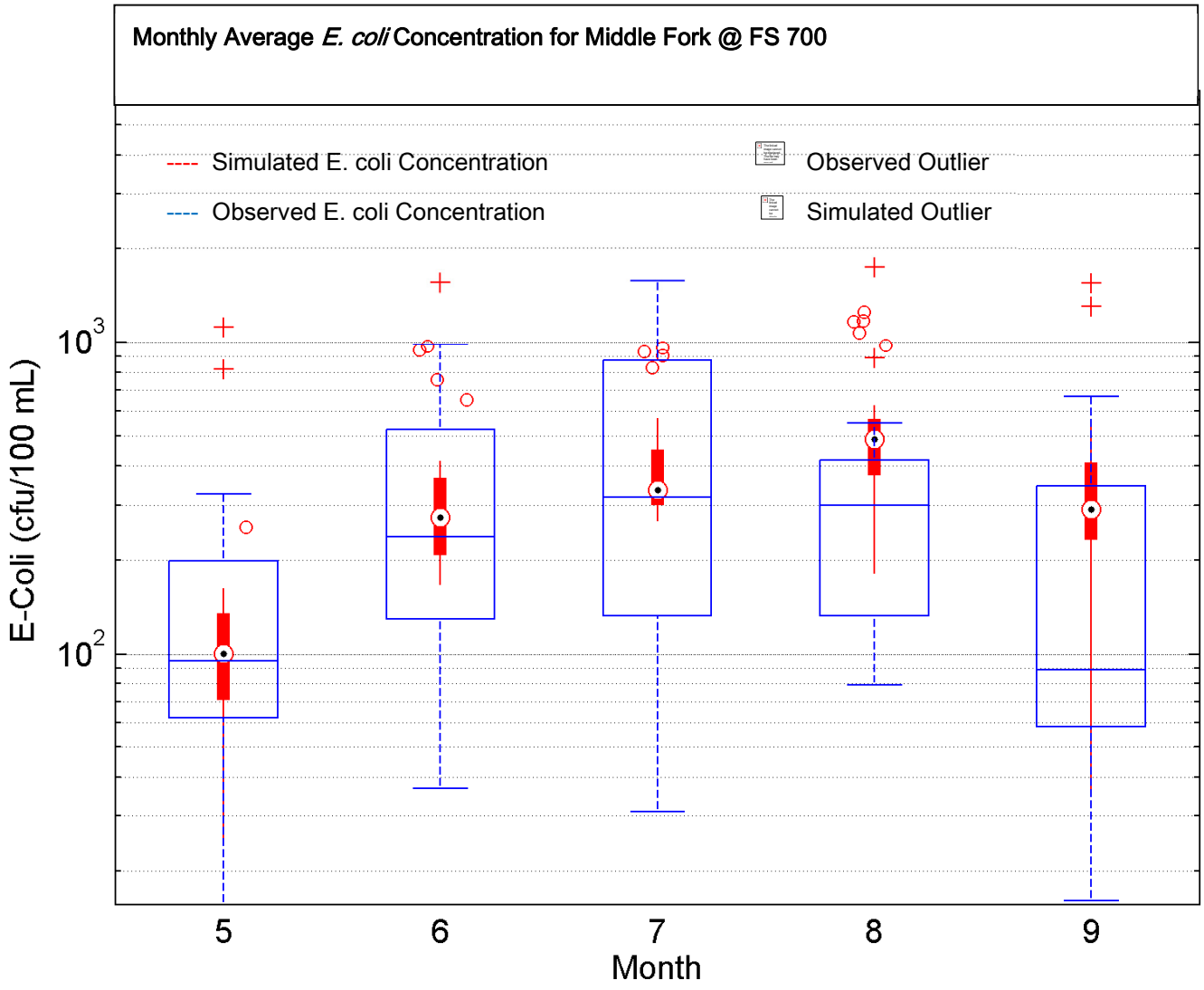


Figure 2-7. Simulated and Observed *E. coli* Monthly Concentrations in the Impaired Reach of Middle Fork Crow Creek.

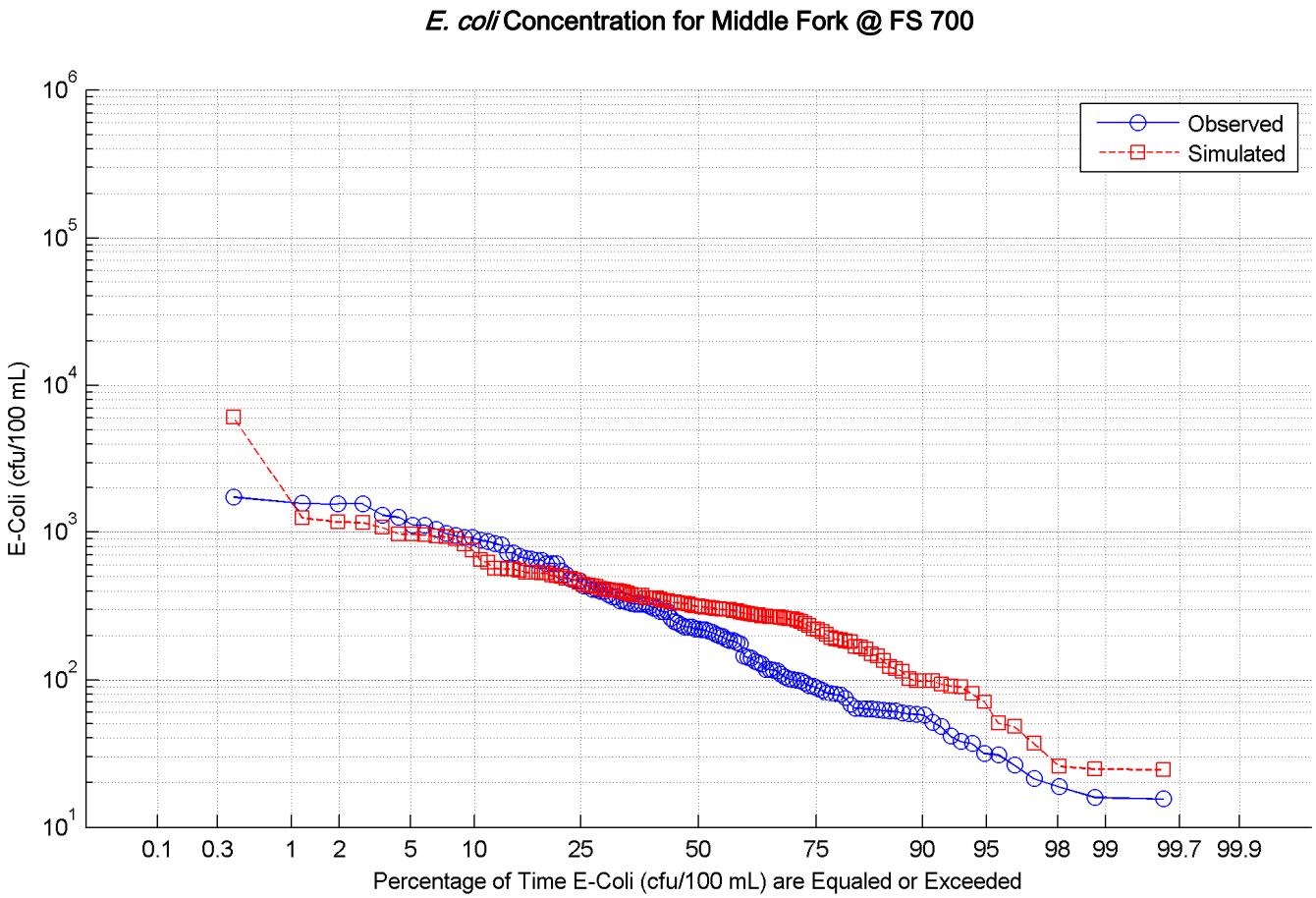


Figure 2-8. Concentration-Duration Curve in the Impaired Reach of Middle Fork Crow Creek.

2.2.3 Source Assessment

Sources to the endpoint of the impaired segment of Middle Fork Crow Creek represent the entire project area. Results from the HSPF model application showed that 88.5 percent of the loading within the project area is linked to runoff, and the other 11.5 percent are linked to direct defecation from wildlife and livestock. Table 2-5 illustrates the source by flow regime (further described in Chapter 3.0). Sources such as direct defecation or illicit RV dumping would likely have more impact during the low flows, while wash-off of bacteria from the land would likely occur during high flows.

Table 2-5. Source Assessment of *E. coli* Load by Flow Regime (Percent)

Percent Contribution	High	Wet	Mid	Low	Dry	Total
Direct	0.2	2.3	11.3	40.8	65.9	**7.8**
Indirect	99.8	97.7	88.7	59.2	34.1	**92.3**

3.0 TOTAL MAXIMUM DAILY LOAD AND ALLOCATIONS

Load duration curves (LDCs), which represent the allowable daily load under any given flow condition, were used to represent the loading capacity and allocations of each impaired reach. This approach results in a flow-variable target that considers the entire flow regime within the time period of interest. Five flow intervals were identified for each reach, and the loading capacity and allocations were developed for each flow interval. The five flow intervals were high (0–10 percent), moist (10–40 percent), midrange (40–60 percent), dry (60–90 percent), and low (90–100 percent), in adherence to guidance provided by the EPA [2007]. The loading capacities were based on the geometric mean standard.

The HSPF model application was used to simulate flow and bacteria concentrations at the endpoints of the impaired segment. Model simulations from the summer recreation season were used to calculate the TMDL and associated components for the summer recreation season TMDLs, respectively. TMDL allocations are based on the most recent 5 full years of data (2010 through 2014).

3.1 LOADING CAPACITY

The TMDL is the loading capacity of a reach and is the sum of the load allocation (LA), the wasteload allocation (WLA), and a MOS, shown in Equation 3-1.

$$\text{TMDL} = \text{LA} + \text{WLA} + \text{MOS} \tag{3-1}$$

LDCs were used to represent the loading capacity. The flow component of the loading capacity curve is the running 60-day geometric mean flow of the simulated daily average flows, and the concentration component is the applicable *E. coli* concentration target. The loading capacities presented in the TMDL tables are the products of the 95th percentile simulated flow in each flow interval, and the applicable *E. coli* concentration target, and a unit conversion factor. Loading capacities developed for the impaired segment are for the summer recreation season, and are, therefore, based on the 126 org/100 mL criterion (in effect from May 1 through September 30). This report is written to include data from 2003 through 2014 (further data from 2015 is presented in Appendix A). These data only included winter recreation season samples from the months of April and October. These April and October concentrations were well below the winter recreation season *E. coli* target of 630 org/100 mL standard (in effect from October 1 through April 30). The low concentrations in April and October suggest concentrations from November through March also remain low; therefore, TMDL tables and LDCs were not developed for the winter recreation season.

3.2 MARGIN OF SAFETY

The MOS is an unallocated load intended to account for uncertainties in the allocations (e.g., monitored or modeled loads from tributary streams and the effectiveness of controls). An explicit MOS was calculated for each flow zone as the difference between the 50th percentile load and the minimum load. A substantial MOS is provided using this method, because the loading capacity is typically much less at the minimum flow of a zone when compared to the midpoint [EPA, 2007]. Because the allocations are a direct function of flow, accounting for potential flow variability is an appropriate way to address the MOS.

3.3 WASTELOAD ALLOCATION

The wasteload allocation (WLA) is the sum of the permitted point-source allocations within each reach. A statewide stormwater permit exists in Wyoming; however, there are no industrial or MS4 areas in the project area. Road construction can occur in the project area but does not likely contribute *E. coli* to the impaired segment. Because no permitted point sources exist upstream of the impaired segment, the WLA was set to 0.

3.4 LOAD ALLOCATION

The load allocation (LA) represents the load allowed from nonpoint sources. The LA was calculated as the loading capacity minus the MOS and the WLA.

3.5 LOAD REDUCTIONS TO MEET TOTAL MAXIMUM DAILY LOAD

The percent load reductions needed to meet the loading capacity in each flow interval were calculated to provide a sense of the overall magnitude of the reductions needed. The percent reductions also help focus management recommendations; if higher reductions are needed in a certain flow interval, management practices should focus on the sources that most likely exist under those flow conditions. Exceedances of the *E. coli* target during high flows are typically caused by indirect pollutant sources that reach surface waters through watershed runoff. Low-flow exceedances are typically caused by direct pollutant loads or sources in close proximity to the stream, such as direct defecation by wildlife or livestock in the stream channel or failing septic systems [EPA, 2007].

To calculate the percent reductions needed, the current load in each flow zone was approximated by the 60-day running geometric mean of the daily simulated load at the 95th percentile within that flow interval. The load reduction required to meet the TMDL in each flow zone was then calculated by subtracting the loading capacity from the current load. The overall percent reduction required for all flow regimes in an impaired reach was a weighted average and was calculated by multiplying the fraction of time flows that are equaled or exceeded in each flow zone (0.1 for high, 0.3 for moist, 0.2 for midrange, 0.3 for dry, and 0.1 for low) by the load reductions and current loads for each flow zone and calculating the quotient of the two flow-weighted values. Required reductions are summarized for the summer recreation season only.

3.6 LOAD DURATION CURVES/TOTAL MAXIMUM DAILY LOAD TABLES

This section presents the LDCs for the summer recreation season, w shown in Figure 3–1, and the TMDL tables for the summer recreation season, as shown in Table 3–1. The loading capacity is represented by the green line, which represents a flow duration curve times the criteria and a conversion factor. The figure illustrates the observed *E. coli* loads (blue circles) and the simulated *E. coli* loads (red boxplots). Monitoring data from 2010 through 2014 were used to calculate the observed loads by multiplying the observed 60-day running geometric mean concentration by the simulated flow at the applicable flow percentile. The geometric means were means of the observed data within that 60-day time period, if more than five samples separated by a minimum of 10 days were available. Data that are higher than the loading

capacity curve exceed the water quality criterion, and those below the curve are in compliance. Based on the LDC and TMDL table, reductions are required during both across all flow regimes.

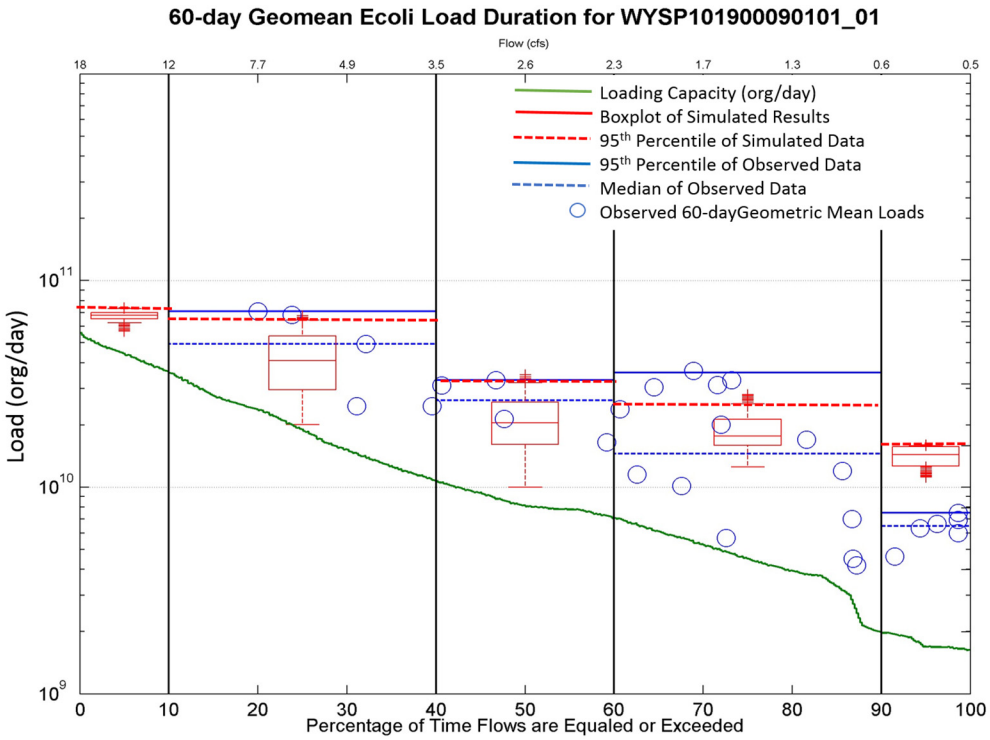


Figure 3-1. Middle Fork Crow Creek Load Duration Curve Representing Geometric Mean *E. coli* Loads Based on the Summer Recreation Season *E. coli* Target.

Table 3-1. Summer Recreation Season Total Maximum Daily Load for Middle Fork Crow Creek

***E. coli* TMDL Component (expressed as 10^9 org/day)**	**Flow Zone**				
	High	**Moist**	**Midrange**	**Dry**	**Low**
	> 11.8 cfs	**11.8–3.5 cfs**	**3.5–2.3 cfs**	**2.3–0.6 cfs**	**< 0.6 cfs**
LA	45.8	25.3	9.5	4.4	1.9
WLA	0.0	0.0	0.0	0.0	0.0
MOS	8.0	8.3	1.0	2.5	0.1
TMDL	53.8	33.6	10.5	6.9	2.0
Current Load	73.2	64.3	32.0	25.5	15.9
Load Reduction	19.4	30.7	21.5	18.6	13.9
% Reduction	27	48	67	73	87
Overall Reduction Required = 53%					

4.0 SEASONALITY

Monthly precipitation, stream flows, and *E. coli* concentrations in the Middle Fork Crow Creek project area vary seasonally. The maximum precipitation generally occurs in the spring, as discussed in Section 1.2.1. Similarly, flows and *E. coli* in the project area were typically highest in Middle Fork Crow Creek during the late spring and early summer months and lowest during late summer and early fall months. Figures that show monthly flow and *E. coli* are included in Section 1.3.

Figure 4-1 illustrates a load duration curve with loading capacity calculated by using HSPF simulated flow. This plot shows observed loads by month and differs from the TMDL LDC in that it was created by using all individual *E. coli* samples collected from 2003 through 2014, not including replicate data, as opposed to 60-day geometric mean data. Note that impairment is not determined based on single samples. Exceedances of the 126 org/100 mL occur during every month of the summer recreation season, from May 1 through September 30.

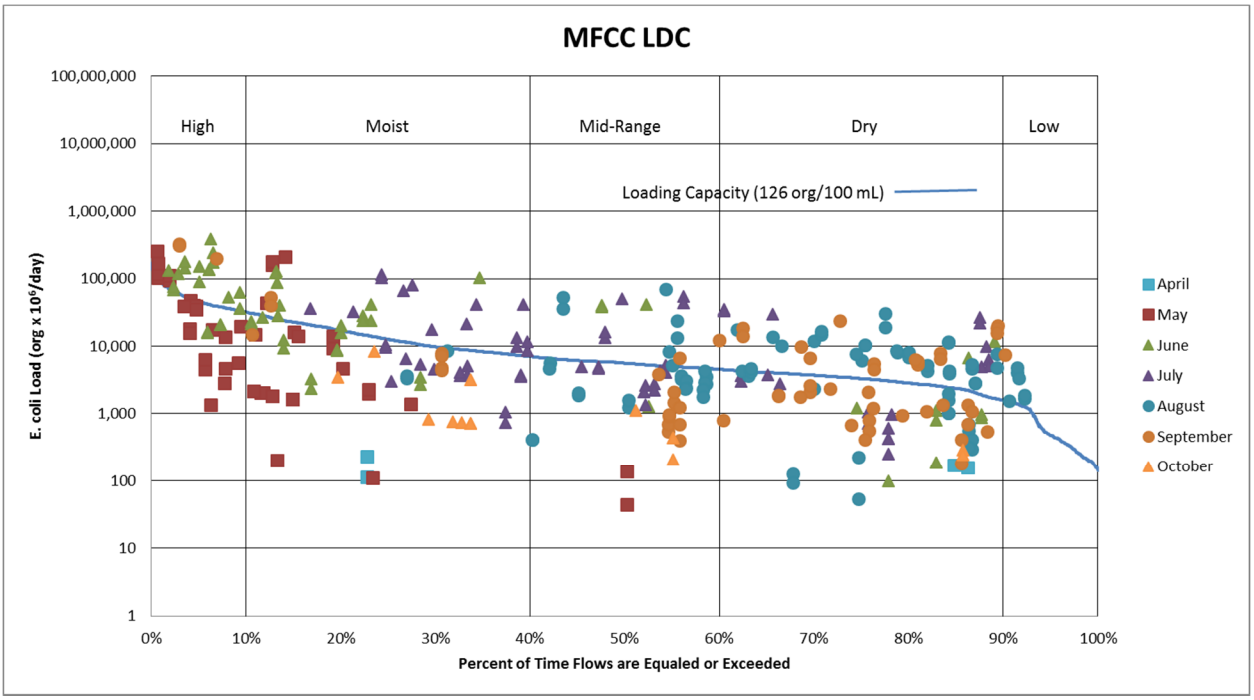


Figure 4-1. Load Duration Curve Showing Monthly Variation of Single-Sample-Based Load Exceedance Created Using All *E.coli* Data Without Replicates.

The LDC approach to develop the TMDL allocations for five flow zones accounts for the seasonal variability in flow and *E. coli* loads (e.g., the high-flow zone contains flows that primarily occur in May and June). The TMDL itself is seasonal, because the summer recreation season *E. coli* target is lower (i.e., more protective) than the winter recreation season *E. coli* target.

Accounting for seasonality is critical for a bacteria TMDL because of the seasonal differences in land-use practices. Within the project area, livestock are commonly moved onto the USFS land of the project area in the beginning of June and removed in the fall. This change in land management during the summer months introduces a seasonal component to bacteria accumulation rates in the watershed. This seasonal pattern is addressed in the TMDL with the LDC approach that is applied separately to the summer and winter seasons. Practices should be applied that reduce both direct and indirect sources of *E.* coli because reductions are required for high and low flows in the LDC. The required reductions in the high flow zones represent more indirect sources, and reductions that are required in the low flow zones represent more direct sources.

Seasonality was also addressed by using a continuous simulation. Bacteria accumulation in the model accounted for seasonality by accounting for the seasonal movement of wildlife and livestock (i.e., wildlife migration or cattle grazing allotment rotations). Modeled bacteria inputs are far higher (2 to 4 times) during the months of June through September because of the influx of animals to grazing land and the recreation that occurs during these months. The model calibration also accounted for seasonality by calibrating to duration curves, daily time series, and monthly averages. This report is written to include data through 2014. These data only included winter recreation season samples from the months of April and October. April and October data suggest that concentrations during the winter recreation season remain well below the *E. coli* target of 630 org/100 mL. Post-2014 data are summarized in Appendix A.

5.0 PUBLIC PARTICIPATION

The efforts to facilitate public education, review, and comment while developing the Middle Fork Crow Creek Watershed TMDL included two public meetings. The first public meeting was held November 18, 2015, in Cheyenne, Wyoming, to discuss the project and to interact with stakeholders. The meeting was advertised in the Cheyenne and Casper newspapers 30-days in advance, and announced on the WDEQ website. Eleven people attended the meeting. They represented the USFS National Forest grazing permit holders, the LCCD, the Cheyenne Bureau of Public Utilities (BOPU), two environmental engineering consultant companies, and WDEQ. Presentations were given by LCCD, RESPEC, and WDEQ. LCCD presented information on water quality monitoring and the implementation of BMPs in the watershed. RESPEC discussed the development of the TMDL, and presented the draft conclusions of the document. WDEQ gave a presentation on the Clean Water Act and Wyoming Water Quality Rules and Regulations. The second public meeting was held on July 13, 2016, in Laramie, Wyoming, to present the final TMDL, responses to public comments, and the final draft of the implementation plan. It was advertised in Cheyenne and Casper 30-days in advance, and will be announced on the WDEQ website. Stakeholders will also be notified individually about the meeting.

Public meetings are essential to the TMDL process because they allow TMDL developers to interact and exchanges ideas with local people living and working in the watershed affected by the water quality impairment and TMDL process. Meetings were open to the general public and included a TMDL presentation followed by a question and answer period. Public meetings were scheduled to meet the demands of participating stakeholders and the project schedule, and were held in Cheyenne and Laramie, Wyoming, to maximize public involvement. Sign-in sheets were used to identify meeting attendees and comment cards were distributed at the public meetings as a forum for the public and other stakeholders to provide input regarding the TMDL project.

A Technical Advisory Committee (TAC) of stakeholders was established. This committee reviewed and provided input on the final TMDL document. Stakeholder meetings were held to discuss TMDL development, provide editorial comments, and develop an implementation plan. A webpage hosted by WDEQ was used to disseminate information about the project and continues to provide a project description and meeting announcements. The webpage also allows the TMDL, implementation plan, and supporting documentation to be available to the stakeholders and public.

Stakeholders performed several roles in TMDL development for this project. They were contacted individually during TMDL development to obtain information used to calculate *E. coli* loadings, identify pollution sources, and quantify pollution sources. They were given 2 weeks to review and comment on the draft TMDL before the public-notice period. WDEQ and RESPEC responded to their comments, and discussed their responses with them individually before the TMDL went out to public notice. Finally, they provided input on the implementation plan. Stakeholder outreach will be done mostly on an individual basis through meetings, phone calls, and email. Stakeholders include representatives from the BOPU, Laramie Rivers Conservation District (LRCD), LCCD, USFS, Wyoming Game and Fish Department (WGFD), and WDEQ. Information packets were provided to the TAC members by the WDEQ before each meeting. Much of the data used to development the TMDL were obtained from these groups.

6.0 MONITORING STRATEGY

During and after management practice implementation, monitoring will be necessary to evaluate the TMDL attainment. The purpose of monitoring is to decrease TMDL uncertainty, evaluate TMDL attainment, and evaluate BMP effectiveness. Currently, the Laramie County Conservation District has an approved sampling and analysis plan that is in place to ensure that chemical, physical, and biological data are valid under the "Credible Data Law" [WDEQ, 2013]. The conservation district that has been monitoring the impaired segment historically collected five individual samples in a 30-day period to meet the data needs for evaluating the previous 30-day geometric mean *E. coli* target. This data collection pattern may change now that the criterion has changed to require a 60-day geometric mean of the bacteria data. The location that the conservation district has been sampling is well positioned to evaluate the TMDL in the future. Additional monitoring during winter recreation season months (October through April) would be helpful to further assess the condition of the stream during this time. Additionally, extending monitoring upstream and downstream of the impairment would be beneficial.

Continuous discharge data across a broad range of flows improves load calculations. Future monitoring should include additional synoptic discharge measurements at the existing water quality sampling location and at new sites to fill in data gaps upstream and downstream of the impaired segment endpoints in the watershed. Continuous-stage recorders should be installed at key locations in the watershed, and stage-discharge relationships could be developed to convert continuous stage to continuous flow. Relatively low-cost, low-maintenance technologies are available to record continuous stage. Synoptic and continuous flow data will increase the accuracy in future load calculations and the evaluation of BMPs and implementation practices.

Monitoring BMP effectiveness helps evaluate the adequacy of implementation strategies that are targeted to reduce bacteria loads or transport. Monitoring strategies depend on the type of BMP but typically include water quality sampling and discharge measurements upstream and downstream of the BMP. Optimally, historic *E. coli* and flow data would exist upstream and downstream of BMPs to allow for a robust trend and BMP effectiveness analysis. BMP effectiveness data will improve the understanding of bacteria implementation and management measures. These data will increase the knowledge base that will help watershed managers select the most appropriate BMPs that are targeted toward local watershed characteristics.

The WDEQ will use this monitoring strategy to reevaluate the TMDL as implementation proceeds. This evaluation will occur at a minimum of every 5 years, as outlined in the WDEQ TMDL work plan [WDEQ, 2008]. The WDEQ will notify the EPA, and a new public review will be made available if any changes or adjustments are needed after the reevaluation.

7.0 REASONABLE ASSURANCE

The restoration strategy addresses the *E. coli* load reductions needed for the impaired segment to reach water quality standards. The required overall load reduction was 53 percent during the summer recreation season and is represented in Table 7-1. Reductions are required in all flow zones for the impaired reach during the summer recreation season. Any samples collected during the winter recreation season have been below well the winter recreation season *E. coli* target of 630 org/100 mL, and, therefore, winter reductions are not discussed in this chapter.

Table 7-1. Load Reductions Needed

Overall Reduction Required (%)	Load Reductions Required By Flow Zone (%)				
	High	Moist	Midrange	Dry	Low
53	27	48	67	73	87

7.1 EXISTING WATERSHED MANAGEMENT EFFORTS

Multiple conservation accomplishments and BMPs have already been implemented in the project area. Three off-site water developments were installed to help distribute grazing pressure. Additionally, 3,000 feet of buck-and-pole fence across 42 sites has been installed to help control off-road vehicle damage in sensitive wetland/riparian areas. Also, some minor reclamation work has been completed at several unauthorized stream crossings. Most of the projects listed were implemented between the summer of 2013 and 2014, but some of the projects were done as early as June 2012 [Ley, 2015a; 2015b]. The Crow Creek Watershed Plan was written in 2004 [Laramie County Conservation District, 2004] and amended in 2007 [Laramie County Conservation District, 2007]. For the upper watershed, the plan outlines major impacts as forest management, lifestock grazing, intense recreational uses, and development for small acreage housing. The amendment lists many water quality efforts, including grazing reductions, sampling, and public and stakeholder meetings [Laramie County Conservation District, 2007].

7.2 EVALUATION OF MANAGEMENT SCENARIOS

A variety of BMPs could be considered in developing a water quality management implementation plan for the project area to reduce the HSPF-identified bacteria sources. These BMPS could include practices such as riparian forest buffers, riparian area designation, sanitary guidelines for campers, equipment limitations for stream wetlands/bogs/wet meadows, revegetation, stream-channel protection, forest stand condition improvement, and grazing allotment monitoring and evaluation. For this project, the following management scenarios were simulated for the impaired segment using the model application:

1. **Indirect Loads:** decrease load delivered to the stream by 75 percent.
2. **Direct Defecation:** decrease direct defecation to waterbodies by 75 percent.

Individual percent reductions are shown for each management scenario. Because the indirect loads are independent of the direct loads, the total reduction can be summed to derive the cumulative reduction. The reduction of direct defecation would be expected to have a more substantial impact during low flows, and the reduction of indirect loads would be expected to have a more substantial impact during high flows. The simulated reductions from the individual BMPs provide watershed managers the ability to assess the relative efficiency of implementing the individual BMP scenarios. The cumulative percent reduction represents possible simulated load reductions from all BMP management scenarios. The management scenario reductions, shown in Table 7-2, were sufficient to meet the required reductions. The simulated cumulative load reduction is higher than the required reduction, which provides reasonable assurance that the required reductions are attainable. Improved stream and riparian condition would also further decrease bacteria loads to the stream.

Table 7-2. Percent Reductions From Simulated *E. coli* Best Management Practices (Total Maximum Daily Load Time Period)

Scenario	Percent Reduction
Indirect Source Reduction Scenario	57.7
Direct Source Reduction Scenario	4.8
Cumulative Scenario	62.5

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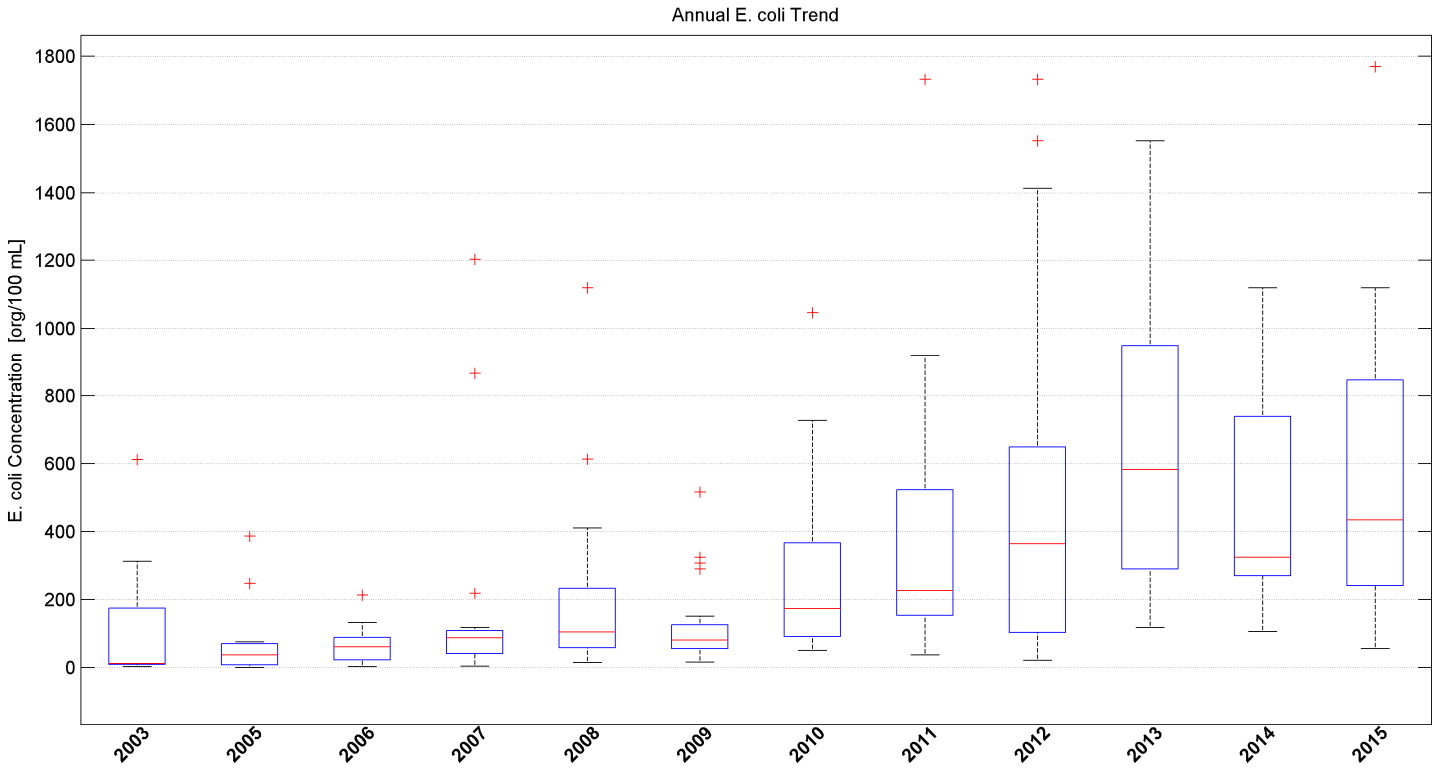
APPENDIX A
SUMMARY OF 2015 DATA

Laramie County Conservation District collected *E. coli* samples on 21 dates between February 18, 2015, and December 1, 2015. Single samples are shown in Table A-1. Similar to the *E. coli* data summarized in the TMDL report, all single samples that were collected during the 2015 winter recreation season were at concentrations far below the criteria of 630 org/100 mL, with a minimum of 3.6 org/100 mL, an average of 80.1 org/100 mL, and a maximum of 197.9 cfu/100 mL. During the 2015 summer recreation season, the minimum concentration was 56.8 org/100 mL, the average was 607.2 org/100 mL, and the maximum was 1769.7 org/100 mL. 60-day geometric means were calculated for data in a consecutive 60-day period with a minimum of five samples collected and separated by 10 days. The result was two winter recreation season geometric means and seven summer recreation season geometric means. Figure A-1 shows boxplots and summary statistics of each year of single sample summer recreation *E. coli* data, including 2015. Summer geometric mean loads were added to the load duration curve from the TMDL and are shown in Figure A-2.

Table A-1. Single Sample 2015 *E. coli* Data at NFSR700

Date	*E. coli* Concentration (org/100 mL)
2/18/2015	3.6
3/11/2015	10.25
3/23/2015	197.9
4/2/2015	61.75
4/16/2015	187.05
5/7/2015	706.95
5/21/2015	178.2
6/4/2015	658.8
6/18/2015	344.8
7/1/2015	224.85
7/16/2015	290.9
7/30/2015	1769.7
8/13/2015	1119.9
8/27/2015	893.6
9/9/2015	435.2
9/24/2015	56.8
10/8/2015	161.75
10/22/2015	128.15
11/3/2015	50.4
11/19/2015	41.35
12/1/2015	89.9



	2003	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
n	9	19	21	19	21	21	20	20	20	20	5	11
Min	3	1	3	4	16	16	51	38	21	118	106	57
Max	613	387	214	1203	1120	517	1046	1733	1733	1553	1120	1770
25th	10	8	23	42	59	56	92	155	103	291	271	241
Median	12	37	61	88	105	81	174	227	365	583	326	435
75th	176	71	90	110	233	126	368	524	650	951	740	847
Mean	133	62	65	179	194	128	271	396	509	646	498	607

Figure A-1. Annual Boxplots and Summary Statistics of *E. coli* Data.

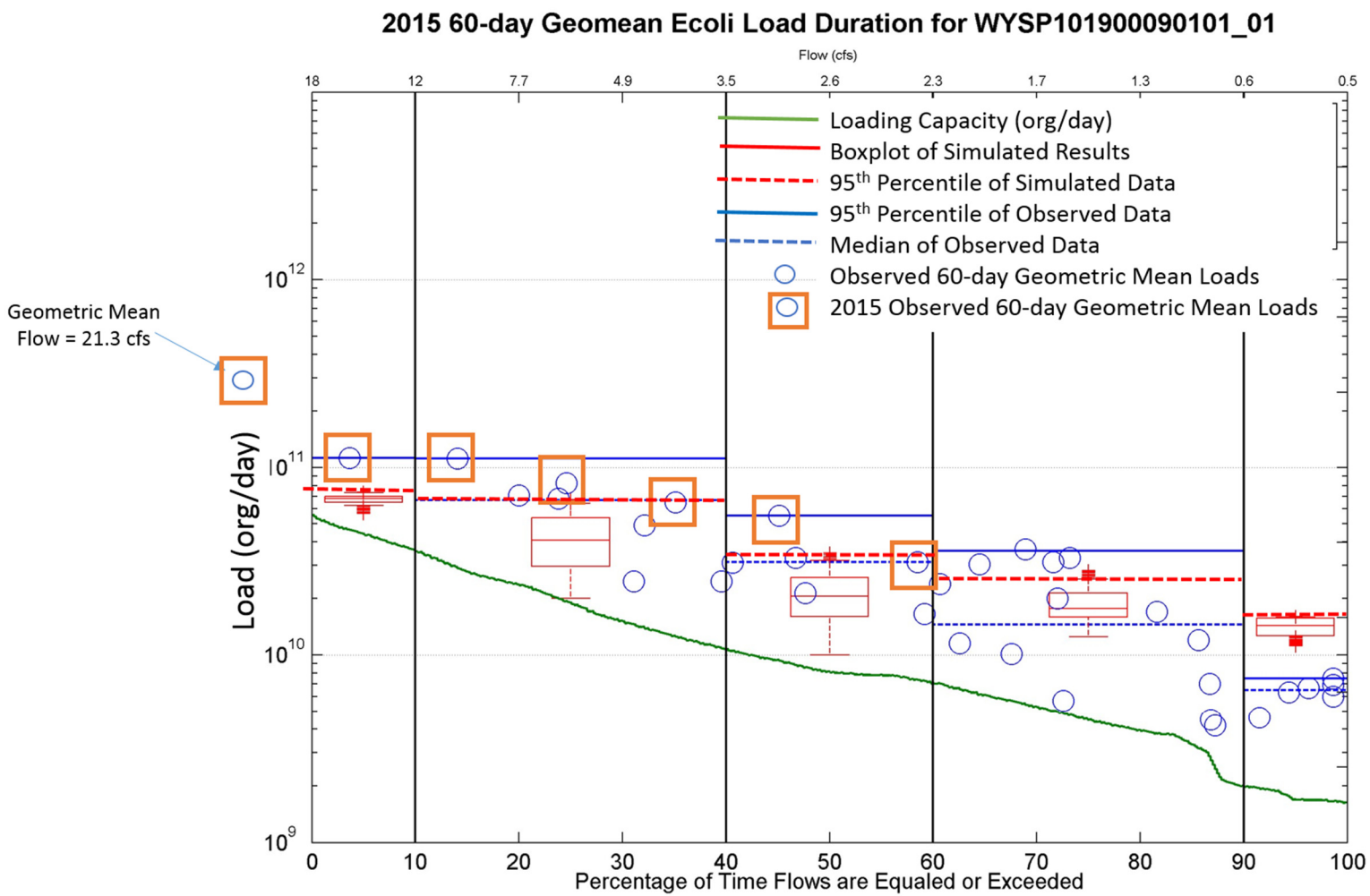


Figure A-2. Summer Recreation Season 60-Day Geometric Mean Load Duration Curve With 2015 Data.

Summer geometric mean loads were added to the load duration curve from the TMDL and are shown in Figure A-1. One load was measured at a flow outside of the extent of the TMDL load duration curve, this point was added to the figure approximately where it would have been located if the pre-2015 geometric flows been higher.

The concentrations of the observed 2015 summer recreation season data were similar to the concentrations from the previous few years of data. The observed loads were all relatively higher than observed loads at/near the same flow from the past observed data. In general, the 2015 data is in line with the data on which the TMDL analysis was based on, leading the conclusion that the TMDL is still valid based on the most recent hydrologic conditions in Middle Fork Crow Creek.