Moneta Divide Natural Gas and Oil Development Project

Draft Environmental Impact Statement

Appendix M

Water Resources Technical Report

January 2018

WATER RESOURCES TECHNICAL REPORT MONETA DIVIDE NATURAL GAS AND OIL DEVELOPMENT PROJECT

Prepared for:

ICF

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Acronyms and Abbreviations

µg/L	micrograms per liter
µmhos/cm	micromhos per centimeter
µS/cm	micro-Siemens per centimeter
Aethon	Aethon Energy Operating LLC
bbl	barrels, each with capacity of 42 US gallons
BLM	Bureau of Land Management
Burlington	Burlington Resources Oil and Gas Company, LP
CFR	Code of Federal Regulations
cfs	cubic feet per second
DMP1	downstream measuring point
DRI	Desert Research Institute
E. coli	*Escherichia coli*
EIS	Environmental Impact Statement
Encana	Encana Oil & Gas (USA), Inc.
EPA	U.S. Environmental Protection Agency
g/L	grams per liter
HUC	hydrologic unit code
mg/L	milligrams per liter
mgal/d	million gallons per day
Moneta Divide Project	Moneta Divide Natural Gas and Oil Development Project
NGS	National Geographic Society
Oasis	Oasis Environmental
pCi/L	picocuries per liter
PRISM	PRISM Climate Group data
Project	Moneta Divide Natural Gas and Oil Development Project
RMP	Resource Management Plan
S	sulfide
SU	standard unit
TDS	total dissolved solid
USBR	U.S. Bureau of Reclamation
USDA	U.S. Department of Agriculture

USGS	U.S. Geological Survey
WOGCC	Wyoming Oil and Gas Conservation Commission
WSEO	Wyoming State Engineer's Office
WSGS	Wyoming State Geological Survey
Wyoming DEQ	Wyoming Department of Environmental Quality
WYPDES	Wyoming Pollutant Discharge Elimination System

1.0 INTRODUCTION

Aethon Energy Operating LLC (Aethon) and Burlington Resources Oil and Gas Company, LP (Burlington) (the applicants) propose to develop new and enhance existing facilities for the exploration and production of oil and gas resources in central Wyoming. The proposed development project is herein referred to as the Moneta Divide Project or Project. The Moneta Divide Project encompasses federal, state, and private land located primarily in Fremont and Natrona counties, approximately 40 miles northeast of Riverton, Wyoming (Figure 1). The southern portion of a proposed Product Pipeline extends into Sweetwater County, Wyoming. Aethon's interest in the Project was acquired from Encana Oil & Gas (USA), Inc. (Encana) in May 2015.

The Moneta Divide Project is located in an area of existing oil and gas development, where oil and gas production has occurred since the early 20th century. Approximately 830 oil and gas wells have been drilled in the Project Area through 2013 (WOGCC 2014). The applicants propose to drill a maximum of 4,250 wells over 15 years, at an average rate of 280 to 300 wells per year. Associated construction would include well pads, access roads, pipelines, compressor stations, and ancillary facilities. The Project Area is composed of the following major components:

- Production Area – The area where the applicants propose to drill and produce oil and gas resources in their respective leaseholds and construct associated facilities.
- Treated Water Discharge Pipeline Corridors to Boysen Reservoir – The area where the applicants propose to construct two Treated Water Discharge Pipelines to deliver treated water to Boysen Reservoir.
- Disposal Areas – The area where the applicants propose to drill disposal wells and associated facilities to inject produced water concentrate.
- Product Pipeline Corridor – The area where the applicants propose to install a Product Pipeline to bring natural gas from the Production Area to the Interstate-80 corridor for sale.

In compliance with the National Environmental Policy Act of 1969, as amended, the Bureau of Land Management (BLM) is preparing an Environmental Impact Statement (EIS) to address potential effects of the Moneta Divide Project. This report describes the water resources analysis area (analysis area) and summarizes the available precipitation, surface water, groundwater, and produced water data in the analysis area to support the BLM's preparation of the EIS. The Project location and boundaries of the Production Area, Disposal Areas, Treated Water Discharge Pipeline Corridors, Product Pipeline, and water resources analysis area are shown on Figure 1.

This report, which was originally prepared in 2015, has been updated with 2017 data on surface water discharge. The remainder of the report uses the same data and period of record as the 2015 document. The 2017 discharge data, derived from the discharge monitoring reports (Wyoming DEQ 2017) are relevant for the analysis in the EIS.

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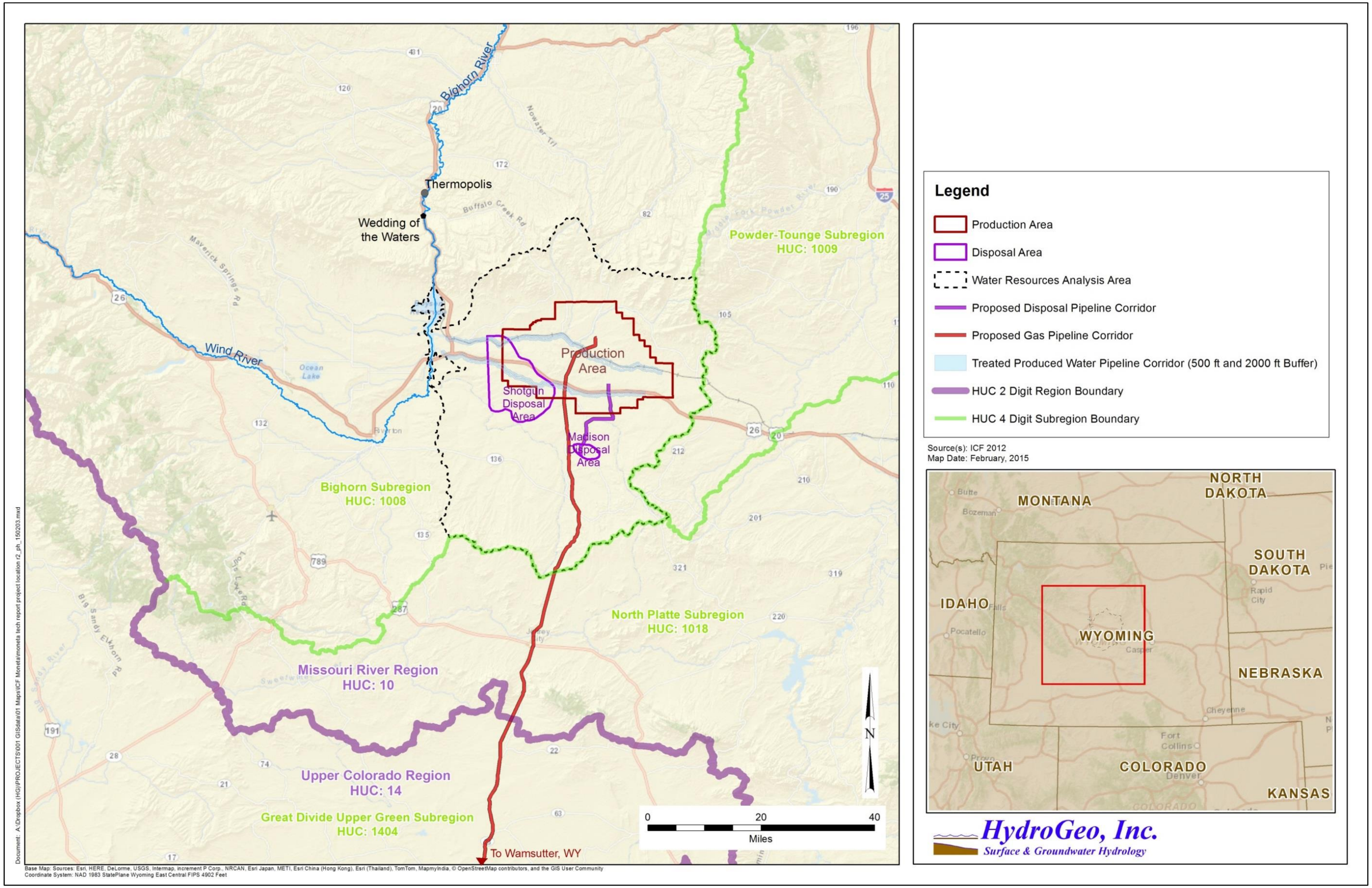
Figure 1. Project Location



Source: ICF 2012

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2.0 OVERVIEW

The analysis area includes areas where the proposed activities of the Project could affect existing surface water and groundwater resources. Specifically, the analysis area includes Boysen Reservoir and the Muskrat, Poison, and Badwater creek drainages (Figures 1, 5, and 6).

Surface water and groundwater resources in the analysis area are used for domestic and municipal water supplies, stock watering, and irrigation. Surface water is also an important resource for aquatic life and other wildlife. Boysen Reservoir is used for multiple purposes, including recreation, fishing, electrical power generation, and downstream agricultural and municipal water supplies.

Descriptions of the surface water and groundwater resources in the analysis area were obtained from several sources, including data publicly available on websites from the following agencies:

- U.S. Geological Survey (USGS)
- Wyoming Department of Environmental Quality (Wyoming DEQ)
- Wyoming State Engineer's Office (WSEO)
- Wyoming State Geological Survey (WSGS)
- Wyoming Oil and Gas Conservation Commission (WOGCC)
- U.S. Bureau of Reclamation (USBR)
- Visual observations recorded by the civil engineer/hydrologist/hydrogeologists on the HydroGeo Project team
- Descriptions in the Lander, Casper, and Rawlins Resource Management Plans (RMPs)
- Data provided by the applicants (Encana, Aethon, and Burlington)

3.0 PRECIPITATION

The precipitation data were derived from The PRISM Climate Group data (PRISM) (PRISM 2013) and local climatological stations in the analysis area (DRI 2014; USBR 2015). PRISM uses 30-year (1981 to 2010) average annual precipitation data from all available climate stations to create a raster grid of expected average annual precipitation values across a given area. The majority of the analysis area can be classified as semi-arid with annual average precipitation values ranging from approximately 5 to 9 inches. Cooper Mountain and Lysite Mountain to the north and the Bighorn Mountains to the northeast of the Production Area are substantially wetter. The Bighorn Mountains receive an average of 29 inches of precipitation annually. The analysis area PRISM grid and precipitation station locations are shown on Figure 2.

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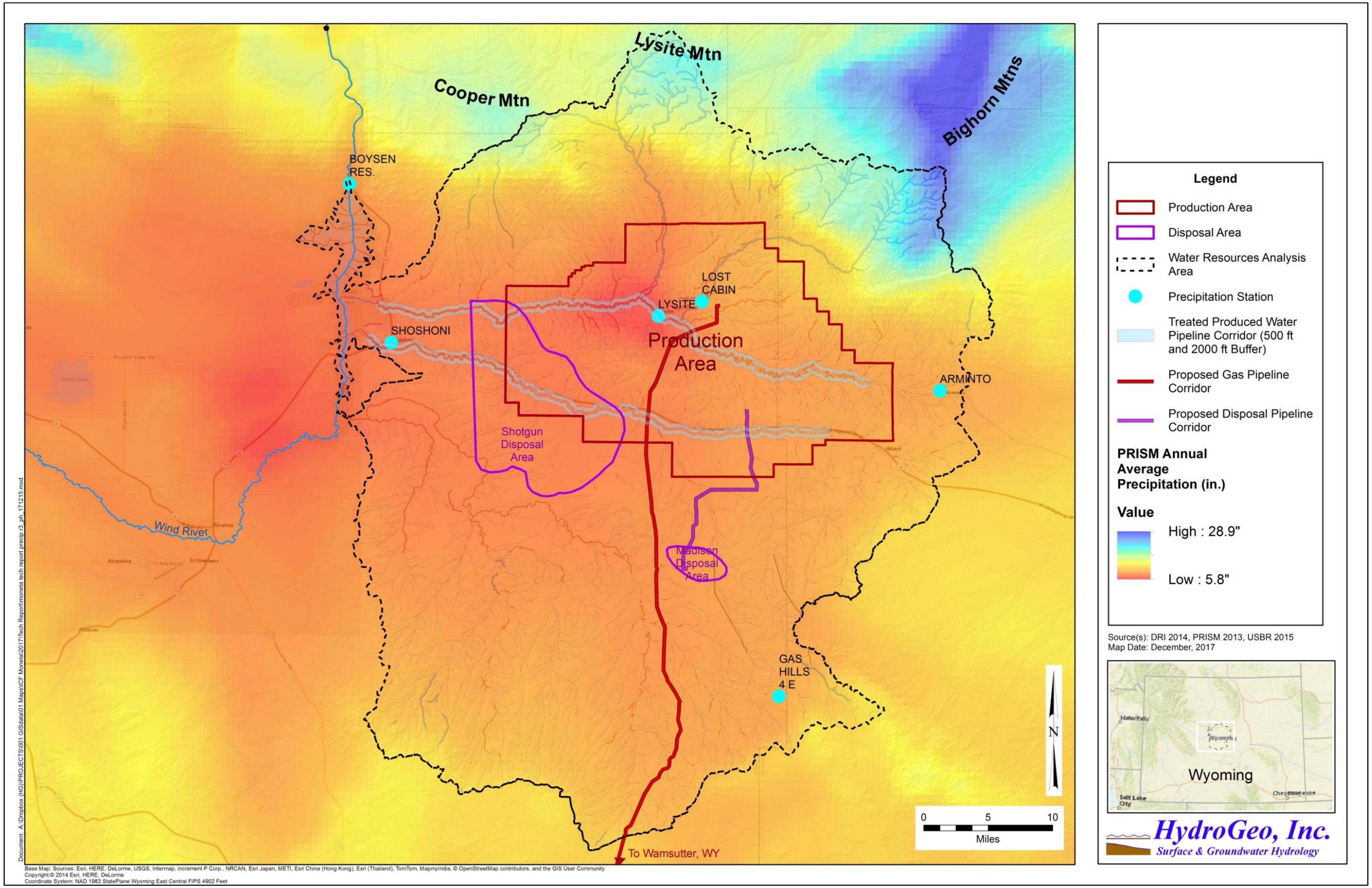
Figure 2. PRISM Grid and Precipitation Stations



Source: DRI 2014; PRISM 2013; USBR 2015

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There are six precipitation stations in the analysis area with historical precipitation data (Figure 2) (USBR 2015):

- Shoshoni (488209)
- Gas Hills 4E (483801)
- Lost Cabin (485734)
- Arminto (480324)
- Lysite (485843)
- Boysen Reservoir.

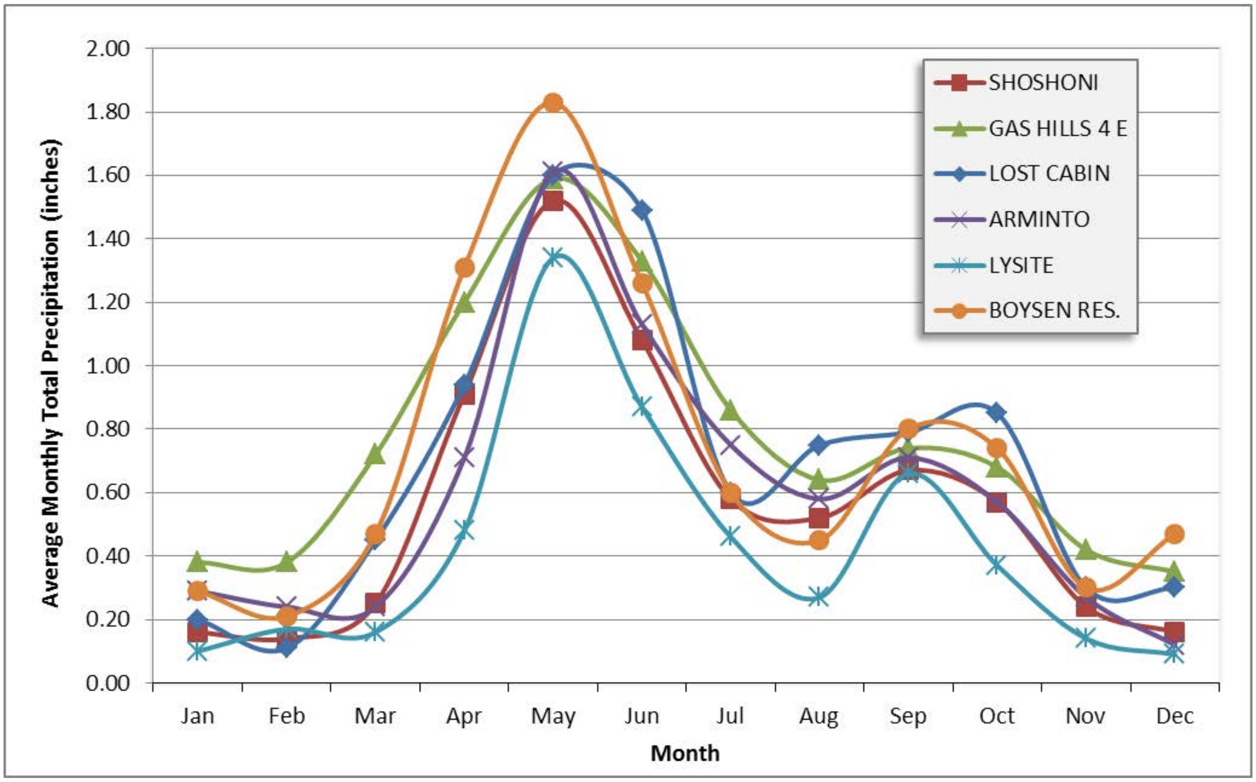
The average annual precipitation values at the precipitation stations in the analysis area range from 5.12 inches (Lysite) to 9.28 inches (Gas Hills 4E). The mean annual precipitation for all stations is 7.52 inches. At all stations, May and June are the wettest months, and the winter months between December and February are the driest. The monthly and annual average total precipitation values for the six precipitation stations in the analysis area are summarized in Table 1 and presented in Figure 3. The period of record for the stations is variable, as shown in Table 1.

Table 1. Analysis Area Climate Stations: Average Monthly and Annual Total Precipitation

Station Name (ID No.)	Period of Record	Average Total Precipitation (inches)												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
SHOSHONI, WYOMING (488209)	3/1931 to 3/2013	0.16	0.14	0.25	0.91	1.52	1.08	0.58	0.52	0.67	0.57	0.24	0.16	**6.81**
GAS HILLS 4 E, WYOMING (483801)	9/1962 to 4/2007	0.38	0.38	0.72	1.20	1.59	1.33	0.86	0.64	0.74	0.68	0.42	0.35	**9.28**
LOST CABIN, WYOMING (485734)	10/1961 to 9/1982	0.20	0.11	0.45	0.94	1.60	1.49	0.60	0.75	0.79	0.85	0.30	0.30	**8.39**
ARMINTO, WYOMING (480324)	10/1949 to 11/1966	0.29	0.24	0.24	0.71	1.61	1.13	0.75	0.58	0.71	0.57	0.27	0.12	**7.23**
LYSITE, WYOMING (485843)	7/1949 to 5/1961	0.10	0.17	0.16	0.48	1.34	0.87	0.46	0.27	0.66	0.37	0.14	0.09	**5.12**
Boysen Reservoir (USBR)	1/1947 to 12/2014	0.29	0.21	0.47	1.31	1.83	1.26	0.60	0.45	0.80	0.74	0.30	0.47	**8.27**
--	Min	0.1	0.11	0.16	0.48	1.34	0.87	0.46	0.27	0.66	0.37	0.14	0.09	**5.12**
	Max	0.38	0.38	0.72	1.31	1.83	1.49	0.86	0.75	0.80	0.85	0.42	0.47	**9.28**
	Mean	0.24	0.21	0.38	0.93	1.58	1.19	0.64	0.54	0.73	0.63	0.28	0.25	**7.52**

Source: DRI 2014; USBR 2015

Figure 3. Average Monthly Total Precipitation for Stations in the Analysis Area



Source: DRI 2014; USBR 2015

4.0 SURFACE WATER HYDROLOGY

4.1 Regional Overview

USGS defines watersheds from larger to smaller units, where a region is the largest unit, followed by subregion, basin, subbasin, watershed, and subwatershed, with identifying hydrologic unit codes (HUCs) of 2, 4, 6, 8, 10, and 12 digits, respectively.

The analysis area occurs in one USGS-defined region north of the Continental Divide, the Missouri River Region (HUC 10). The analysis area is included in the Bighorn (HUC 1008) subregion of the Missouri River Region. The proposed Product Pipeline Corridor straddles the Continental Divide and is included in two regions, the Missouri River Region (HUC 10) and the Upper Colorado Region (HUC 14). The proposed Product Pipeline Corridor is included in three subregions, the Bighorn (HUC 1008) and the North Platte (HUC 1018) subregions in the Missouri River Region and the Great Divide Upper Green (HUC 1404) subregion in the Upper Colorado Region (Figure 1).

Waters from both the Bighorn and the North Platte subregions drain eastward and ultimately flow via the Missouri and Mississippi rivers to the Gulf of Mexico (Atlantic Ocean). Waters from the Great Divide Upper Green River subregion flow via the Colorado River toward the Gulf of California (Pacific Ocean).

The Production Area and the Shotgun and Madison Disposal areas (not including the proposed Product Pipeline Corridor) (Figure 1) lie completely within the Bighorn (HUC 1008) subregion and in the Bighorn basin within the subregion. In the Bighorn basin, the Wind River flows from south to north into Boysen Reservoir. After the Wind River leaves Boysen Reservoir, it becomes the Bighorn River at the "Wedding of the Waters" as it exits Wind River Canyon, near Thermopolis, Wyoming (Figures 1 and 4).

The analysis area encompasses parts of three subbasins, the Badwater (HUC 10080006), and Muskrat (HUC 10080004) subbasins, and the eastern portion of the Lower Wind (HUC 10080005) subbasin (Figure 4). Each of these subbasins lies within the Bighorn basin. Poison Creek is the main drainage in the eastern portion of Lower Wind subbasin. The western portion of the Lower Wind subbasin lies outside of the analysis area to the west of Boysen Reservoir. The main drainages in the analysis area are Badwater, Poison, and Muskrat creeks, which generally flow east to west and drain into Boysen Reservoir (Figures 1, 4, 5 and 6).

Multiple springs exist in the analysis area. Most occur in the uppermost reaches of tributaries to Badwater Creek (Figure 5) and Muskrat Creek (Figure 6). These springs feed perennial headwaters of these tributaries and streams.

Boysen Reservoir (Photo 1) was created by the construction of the earth-filled Boysen Dam across the Wind River between 1947 and 1952 (USBR 2015). After exiting Boysen Reservoir, the Wind River flows northward though Wind River Canyon then becomes the Bighorn River at the "Wedding of the Waters," just south of Thermopolis, Wyoming (Figure 4). The Bighorn River flows northeast into Montana to join the Yellowstone River, which, in turn, flows into the Missouri River.

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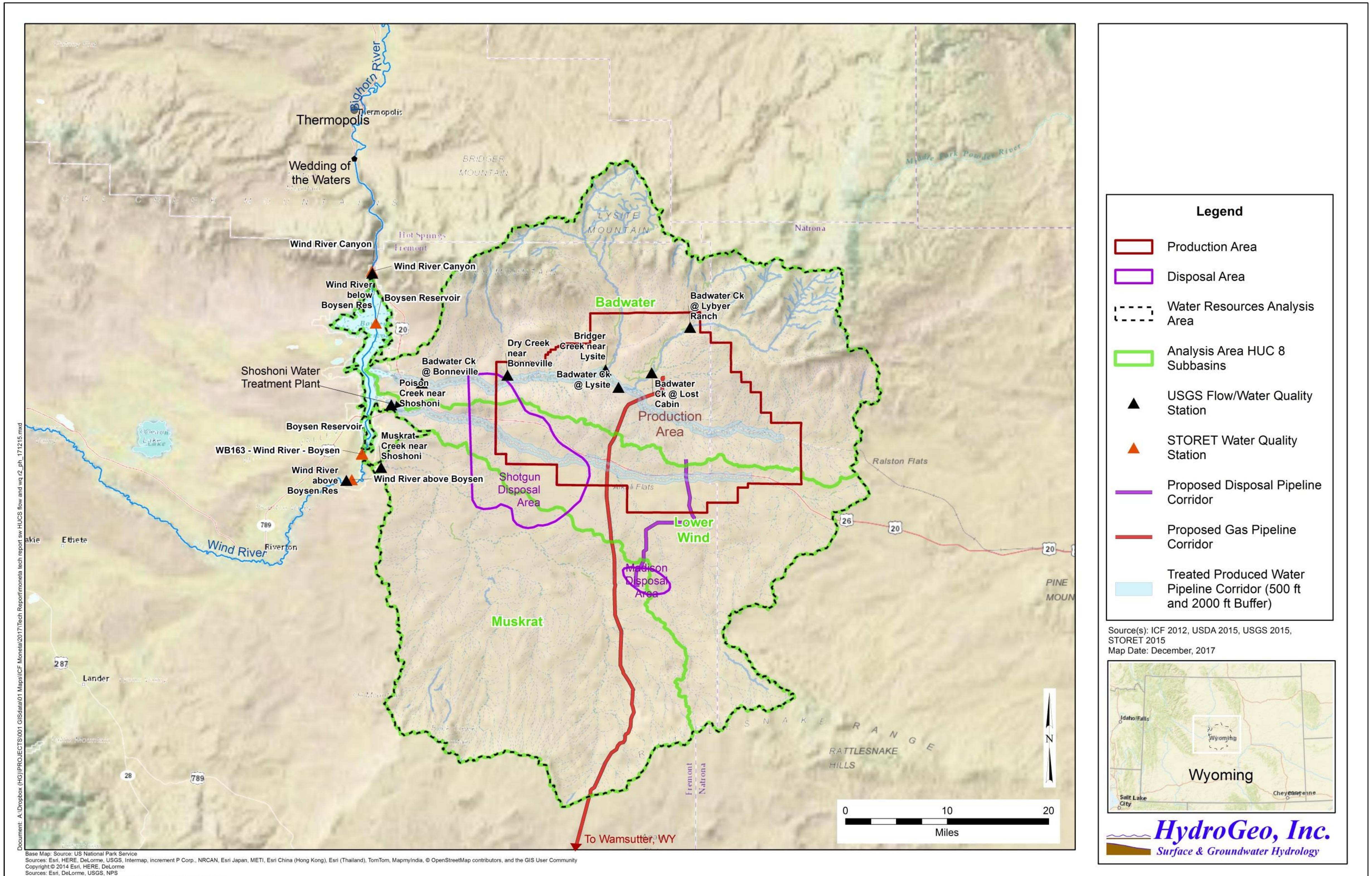
Figure 4. Surface Water Hydrology Map of the Analysis Area



Source: ICF 2012; USDA 2015; USGS 2015; EPA 2015

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Photo 1. Poison Creek Arm of Boysen Reservoir, Wyoming

View of the area where Poison Creek drains into Boysen Reservoir. The banding of soils and vegetation indicate changing water levels. Photo taken August 27, 2013.

4.1.1 Badwater Subbasin

The Badwater subbasin (HUC 10080006) encompasses approximately 856 square miles in the northern portion of the analysis area (Figure 4 and 5). Its drainage network comprises four named watersheds (HUC 10 level): Lower Badwater, Bridger, Upper Badwater, and Alkali creeks, from west to east (Figure 5).

4.1.1.1 Drainages

The Lower Badwater Creek watershed is approximately 245 square miles in areal extent and contains six named drainages: Reservoir, Hoodoo, Dry, Schoening, Dolus, and Badwater creeks (Figure 5). The Upper Badwater Creek watershed is approximately 215 square miles in areal extent and contains seven named drainages: Snyder, Sioux, Clear, Frenchie, Willow, Sand, and Badwater creeks (Figure 5). The main channel of Badwater Creek is approximately 72 miles from its headwaters in the Bighorn Mountains to its terminus at Boysen Reservoir. Badwater Creek has an average gradient of -1.07 percent

The Bridger Creek watershed is approximately 183 square miles in areal extent and contains seven named drainages: Pine, Maimes, Jenks, Meadow, Lysite, Cottonwood, and Bridger creeks

(Figure 5). The main channel of Bridger Creek is approximately 39 miles long from its headwaters on the north side of Lysite Mountain to its junction with Badwater Creek. Bridger Creek has an average gradient of -0.79 percent.

The Alkali Creek watershed is approximately 214 square miles in areal extent and contains four named drainages: Reservoir, Red, E-K, and Alkali creeks (Figure 5). The main channel of Alkali Creek is approximately 37 miles long from its headwaters about 1 mile SSE of Arminto to its junction with Badwater Creek Alkali Creek has an average gradient of -0.40 percent.

4.1.1.2 Reservoirs

The Lower Badwater Creek watershed contains four named reservoirs: Boysen, Bonneville, Days, and Sheep Camp reservoirs. The Upper Badwater Creek watershed contains four named reservoirs: Burlington, Lost Cabin, Okie, and Waterworks Number 3 reservoirs. Sheep Camp Reservoir appears to be decommissioned from aerial photo inspection.

The Bridger Creek watershed contains one named reservoir: Percy Reservoir. The Alkali Creek watershed contains two named reservoirs: Jackpot and Badwater Creek reservoirs. The locations of the named reservoirs and stock ponds are shown on Figure 5.

4.1.1.3 USGS Springs

In the Badwater subbasin, the Lower Badwater Creek watershed contains one unnamed spring, the Bridger Creek watershed contains 19 named springs and 12 unnamed springs, the Upper Badwater Creek watershed contains four named springs and 41 unnamed springs, and the Alkali Creek watershed contains one named spring and three unnamed springs (USGS 2015). The locations of springs in the Badwater subbasin are shown on Figure 5. A summary of spring data, including subbasin, watershed, spring name, source, and map coordinates, is presented in Table 2.

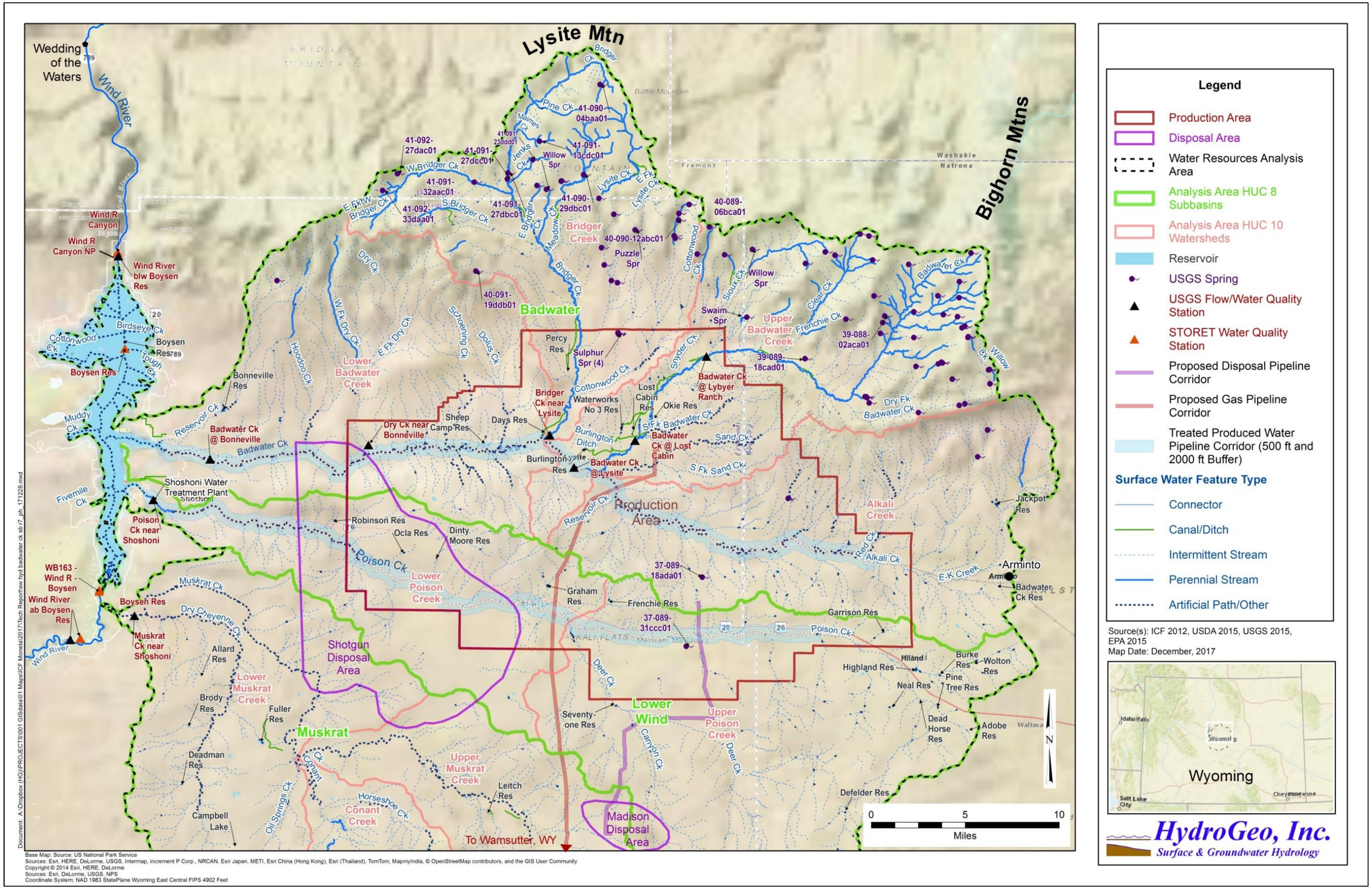
4.1.2 Lower Wind Subbasin (Eastern Portion)

The eastern portion of the Lower Wind subbasin encompasses approximately 503 square miles in the central portion of the analysis area (Figure 4). Its drainage network comprises two named watersheds (HUC 10 level): Lower Poison and Upper Poison creeks (Figure 6).

4.1.2.1 Drainages

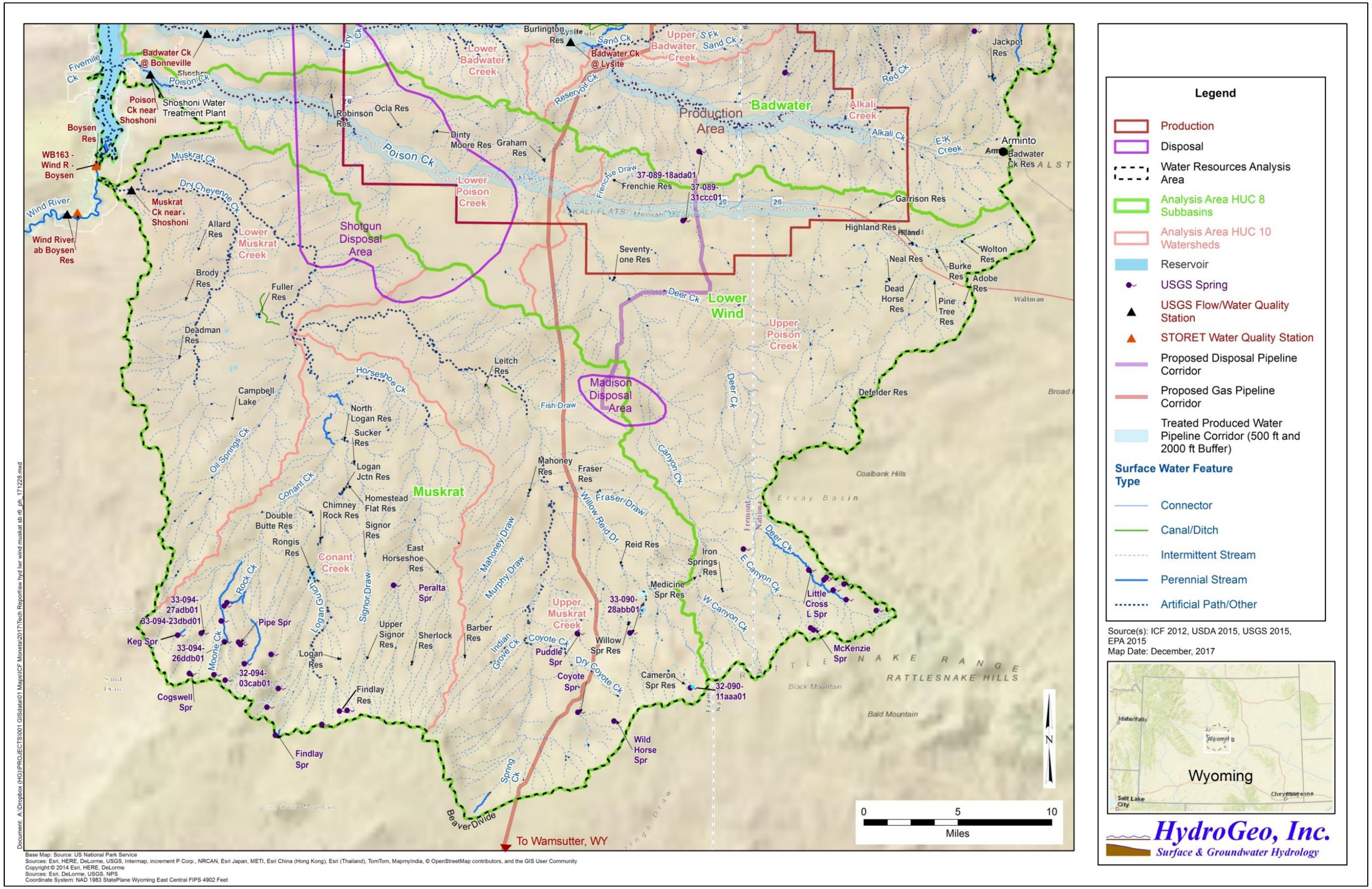
The Lower Poison Creek watershed is approximately 148 square miles in areal extent and contains one named drainage: Poison Creek. The Upper Poison Creek watershed is approximately 354 square miles in areal extent and contains four named drainages: Deer, Canyon, Frenchie Draw, and Poison creeks (Figure 6). The main channel of Poison Creek is approximately 68 miles long from its headwaters about 3.5 miles SSE of Arminto to its terminus at Boysen Reservoir. Poison Creek has an average gradient of -0.40 percent.

Figure 5. Surface Water Hydrology Badwater Subbasin



Source: ICF 2012; USDA 2015; USGS 2015; EPA 2015

Figure 6. Surface Water Hydrology Lower Wind and Muskrat Subbasins



Source: ICF 2012; USDA 2015; USGS 2015; EPA 2015

Table 2. Springs near the Analysis Area

Subbasin	Watershed	Spring Name	Geology Springs Issue From	Geologic Symbol	X Coordinate	Y Coordinate
Badwater	Lower Badwater	T40nR93wS28[1]	Wagon Bed Formation	Twb	1133207.247	1388145.198
Badwater	Bridger Creek	40-089-06bca01[2]	Madison Limestone or Group	Mm	1249000.973	1409535.819
Badwater	Bridger Creek	40-090-12abc01[2]	Madison Limestone or Group	Mm	1246031.581	1405126.651
Badwater	Bridger Creek	40-091-19ddb01[2]	Gallatin Limestone, Gros Ventre Formation and equivalents, and Flathead Sandstone	Cr	1189057.34	1390803.24
Badwater	Bridger Creek	41-090-04baa01[2]	Frontier Formation	Kf	1223956.75	1443184.027
Badwater	Bridger Creek	41-090-29dbc01[2]	Wagon Bed Formation	Twb	1219310.28	1417904.359
Badwater	Bridger Creek	41-091-13cdc01[2]	Sundance Formation	Js	1206945.168	1427261.344
Badwater	Bridger Creek	41-091-23ddd01[2]	Wagon Bed Formation	Twb	1205004.273	1422107.012
Badwater	Bridger Creek	41-091-27dbc01[2]	Chugwater Formation or Group	TRc	1198056.921	1418395.616
Badwater	Bridger Creek	41-091-27dcc01[2]	Chugwater Formation or Group	TRc	1197900.569	1416675.205
Badwater	Bridger Creek	41-091-32aac01[2]	Wagon Bed Formation	Twb	1188598.251	1415772.23
Badwater	Bridger Creek	41-092-27dac01[2]	Bighorn Dolomite	Ob	1167020.194	1418172.782
Badwater	Bridger Creek	41-092-33daa01[2]	Wagon Bed Formation	Twb	1162859.916	1413441.75
Badwater	Bridger Creek	Puzzle Spring[3]	Gallatin Limestone, Gros Ventre Formation and equivalents, and Flathead Sandstone	Cr	1233800.123	1402392.823
Badwater	Bridger Creek	Sulphur Springs[3]	Wind River Formation	Twdr	1229137.78	1373126.807
Badwater	Bridger Creek	Sulphur Springs[3]	Wind River Formation	Twdr	1229207.472	1373052.532
Badwater	Bridger Creek	Sulphur Springs[3]	Wind River Formation	Twdr	1229102.205	1373226.931
Badwater	Bridger Creek	Sulphur Springs[3]	Wind River Formation	Twdr	1228973.246	1373469.383
Badwater	Bridger Creek	T40nR90wS01[1]	Wagon Bed Formation	Twb	1246096.688	1407018.141
Badwater	Bridger Creek	T40nR90wS04[1]	Madison Limestone or Group	Mm	1227811.816	1406785.108
Badwater	Bridger Creek	T40nR90wS05[1]	Tensleep Sandstone and Amsden Formation	PM	1223611.409	1411233.808
Badwater	Bridger Creek	T40nR90wS13A[1]	Gallatin Limestone, Gros Ventre Formation and equivalents, and Flathead Sandstone	Cr	1244733.943	1400738.98
Badwater	Bridger Creek	T40nR90wS13B[1]	Gallatin Limestone, Gros Ventre Formation and equivalents, and Flathead Sandstone	Cr	1245037.92	1400016.274
Badwater	Bridger Creek	T40nR90wS17[1]	Wagon Bed Formation	Twb	1224354.925	1397377.579
Badwater	Bridger Creek	T40nR90wS20[1]	Wagon Bed Formation	Twb	1225100.385	1392547.481
Badwater	Bridger Creek	T40nR90wS28[1]	Wagon Bed Formation	Twb	1228838.53	1387560.705
Badwater	Bridger Creek	T41nR90wS29[1]	Wagon Bed Formation	Twb	1227117.371	1388145.892
Badwater	Bridger Creek	T41nR90wS31A[1]	Wagon Bed Formation	Twb	1213178.211	1416120.424
Badwater	Bridger Creek	T41nR90wS31B[1]	Wagon Bed Formation	Twb	1213025.942	1416049.084
Badwater	Bridger Creek	T41nR91wS36[1]	Wagon Bed Formation	Twb	1206218.575	1414865.894
Badwater	Bridger Creek	Willow Spring[3]	Wagon Bed Formation	Twb	1208859.448	1413793.06
Badwater	Upper Badwater	39-088-02aca01[2]	Oldest gneiss complex	Ugn	1303925.45	1378218.982

Subbasin	Watershed	Spring Name	Geology Springs Issue From	Geologic Symbol	X Coordinate	Y Coordinate
Badwater	Upper Badwater	39-089-18cad01[2]	Wagon Bed Formation	Twb	1281539.235	1366207.348
Badwater	Upper Badwater	Swaim Spring[3]	Wagon Bed Formation	Twb	1265155.893	1377853.231
Badwater	Upper Badwater	T39nR87wS04A[1]	Oldest gneiss complex	Ugn	1324369.492	1378016.207
Badwater	Upper Badwater	T39nR87wS04B[1]	Oldest gneiss complex	Ugn	1326430.546	1375325.968
Badwater	Upper Badwater	T39nR87wS04C[1]	Oldest gneiss complex	Ugn	1325636.734	1374895.758
Badwater	Upper Badwater	T39nR87wS05[1]	Oldest gneiss complex	Ugn	1320399.688	1378573.153
Badwater	Upper Badwater	T39nR87wS06[1]	Oldest gneiss complex	Ugn	1312108.298	1379386.928
Badwater	Upper Badwater	T39nR87wS07[1]	Oldest gneiss complex	Ugn	1312104.874	1372165.745
Badwater	Upper Badwater	T39nR87wS10A[1]	Oldest gneiss complex	Ugn	1327375.355	1372392.469
Badwater	Upper Badwater	T39nR87wS10B[1]	Oldest gneiss complex	Ugn	1327323.448	1372210.463
Badwater	Upper Badwater	T39nR87wS17A[1]	Oldest gneiss complex	Ugn	1319888.182	1365234.755
Badwater	Upper Badwater	T39nR87wS17B[1]	Oldest gneiss complex	Ugn	1320156.22	1365032.855
Badwater	Upper Badwater	T39nR87wS17C[1]	Oldest gneiss complex	Ugn	1318978.418	1364748.544
Badwater	Upper Badwater	T39nR87wS19[1]	Wagon Bed Formation	Twb	1312699.275	1364058.694
Badwater	Upper Badwater	T39nR87wS21[1]	Gallatin Limestone, Gros Ventre Formation and equivalents, and Flathead Sandstone	Cr	1322911.342	1360470.055
Badwater	Upper Badwater	T39nR87wS23A[1]	Gallatin Limestone, Gros Ventre Formation and equivalents, and Flathead Sandstone	Cr	1333375.683	1363166.97
Badwater	Upper Badwater	T39nR87wS23B[1]	Gallatin Limestone, Gros Ventre Formation and equivalents, and Flathead Sandstone	Cr	1333103.742	1363084.902
Badwater	Upper Badwater	T39nR87wS23C[1]	Wagon Bed Formation	Twb	1333488.844	1359169.265
Badwater	Upper Badwater	T39nR87wS31[1]	Wagon Bed Formation	Twb	1313390.903	1351108.125
Badwater	Upper Badwater	T39nR87wS33A[1]	Wagon Bed Formation	Twb	1326452.993	1353561.63
Badwater	Upper Badwater	T39nR87wS33B[1]	Wagon Bed Formation	Twb	1324869.255	1353125.207
Badwater	Upper Badwater	T39nR88wS02[1]	Oldest gneiss complex	Ugn	1303370.02	1376345.004
Badwater	Upper Badwater	T39nR88wS04[1]	Gallatin Limestone, Gros Ventre Formation and equivalents, and Flathead Sandstone	Cr	1293032.473	1377293.452
Badwater	Upper Badwater	T39nR88wS11[1]	Gallatin Limestone, Gros Ventre Formation and equivalents, and Flathead Sandstone	Cr	1302699.537	1373310.691
Badwater	Upper Badwater	T39nR88wS27A[1]	Wagon Bed Formation	Twb	1298398.162	1355554.484
Badwater	Upper Badwater	T39nR88wS27B[1]	Wagon Bed Formation	Twb	1298724.094	1355516.085
Badwater	Upper Badwater	T39nR88wS27C[1]	Wagon Bed Formation	Twb	1298947.722	1355255.836
Badwater	Upper Badwater	T39nR88wS27D[1]	Madison Limestone or Group	Mm	1299573.904	1353783.283
Badwater	Upper Badwater	T40nR87wS15[1]	Oldest gneiss complex	Ugn	1328162.419	1395889.852
Badwater	Upper Badwater	T40nR87wS19[1]	White River Formation	Twr	1310644.915	1392697.283
Badwater	Upper Badwater	T40nR87wS28[1]	Oldest gneiss complex	Ugn	1324892.855	1387863.562
Badwater	Upper Badwater	T40nR87wS32[1]	Oldest gneiss complex	Ugn	1318850.47	1383874.281
Badwater	Upper Badwater	T40nR87wS33[1]	Oldest gneiss complex	Ugn	1324850.049	1383357.912

Subbasin	Watershed	Spring Name	Geology Springs Issue From	Geologic Symbol	X Coordinate	Y Coordinate
Badwater	Upper Badwater	T40nR88wS10[1]	Oldest gneiss complex	Ugn	1297051.403	1401217.686
Badwater	Upper Badwater	T40nR88wS15[1]	Gallatin Limestone, Gros Ventre Formation and equivalents, and Flathead Sandstone	Cr	1299530.41	1400652.818
Badwater	Upper Badwater	T40nR88wS17[1]	Oldest gneiss complex	Ugn	1287206.555	1396192.274
Badwater	Upper Badwater	T40nR88wS19[1]	Oldest gneiss complex	Ugn	1281645.385	1392945.432
Badwater	Upper Badwater	T40nR88wS21[1]	Oldest gneiss complex	Ugn	1289941.127	1395305.033
Badwater	Upper Badwater	T40nR88wS23[1]	Oldest gneiss complex	Ugn	1300554.096	1393940.243
Badwater	Upper Badwater	T40nR88wS35[1]	Oldest gneiss complex	Ugn	1300929.634	1383840.902
Badwater	Upper Badwater	T40nR89wS08[1]	Gallatin Limestone, Gros Ventre Formation and equivalents, and Flathead Sandstone	Cr	1254642.907	1403239.702
Badwater	Upper Badwater	T40nR89wS19[1]	Gallatin Limestone, Gros Ventre Formation and equivalents, and Flathead Sandstone	Cr	1251252.734	1395584.216
Badwater	Upper Badwater	T40nR89wS21[1]	Gallatin Limestone, Gros Ventre Formation and equivalents, and Flathead Sandstone	Cr	1258952.92	1395407.34
Badwater	Upper Badwater	Willow Spring[3]	Wagon Bed Formation	Twb	1266763.715	1396907.884
Badwater	Alkali Creek	37-089-18ada01[2]	Wind River Formation	Twdr	1252671.621	1304889.541
Badwater	Alkali Creek	T38nR87wS02[1]	Chugwater and Dinwoody Formations	TRcd	1332826.532	1346223.929
Badwater	Alkali Creek	T38nR87wS10[1]	Sundance and Gypsum Spring Formations	Jsg	1330064.747	1338679.723
Badwater	Alkali Creek	T38nR89wS25[1]	Wind River Formation	Twdr	1276814.665	1326989.366
Lower Wind	Upper Poison Creek	37-089-31ccc01[2]	Dune sand and loess	Qs	1248170.512	1285463.735
Lower Wind	Upper Poison Creek	Little Cross L Spring[3]	Wind River Formation	Twdr	1283490.433	1187342.846
Lower Wind	Upper Poison Creek	McKenzie Spring[3]	Wagon Bed Formation	Twb	1284870.572	1170526.412
Lower Wind	Upper Poison Creek	T33nR88wS07A[1]	Gallatin Limestone, Gros Ventre Formation and equivalents, and Flathead Sandstone	Cr	1288445.205	1185225.248
Lower Wind	Upper Poison Creek	T33nR88wS07B[1]	Gallatin Limestone, Gros Ventre Formation and equivalents, and Flathead Sandstone	Cr	1287772.54	1184588.118
Lower Wind	Upper Poison Creek	T33nR88wS08A[1]	Granitic rocks of 2,600Ma age group	Wg	1293402.373	1183389.605
Lower Wind	Upper Poison Creek	T33nR88wS08B[1]	Gallatin Limestone, Gros Ventre Formation and equivalents, and Flathead Sandstone	Cr	1290370.773	1181709.392
Lower Wind	Upper Poison Creek	T33nR88wS15[1]	Granitic rocks of 2,600Ma age group	Wg	1302489.376	1175966.734
Lower Wind	Upper Poison Creek	T33nR88wS17[1]	Gallatin Limestone, Gros Ventre Formation and equivalents, and Flathead Sandstone	Cr	1294010.992	1178985.379

Subbasin	Watershed	Spring Name	Geology Springs Issue From	Geologic Symbol	X Coordinate	Y Coordinate
Lower Wind	Upper Poison Creek	T33nR88wS19[1]	Wagon Bed Formation	Twb	1284026.931	1171056.327
Lower Wind	Upper Poison Creek	T34nR89wS33[1]	Wind River Formation	Twdr	1265129.132	1193220.171
Muskrat	Upper Muskrat Creek	32-090-11aaa01[2]	White River Formation	Twr	1250257.734	1154253.984
Muskrat	Upper Muskrat Creek	33-090-28abb01[2]	Wind River Formation	Twdr	1233252.551	1169697.632
Muskrat	Upper Muskrat Creek	Coyote Springs[3]	Wind River Formation	Twdr	1218626.697	1147373.62
Muskrat	Upper Muskrat Creek	Puddle Springs[3]	Wind River Formation	Twdr	1218453.023	1169507.352
Muskrat	Upper Muskrat Creek	Wild Horse Springs[3]	Wagon Bed Formation	Twb	1228764.141	1144890.324
Muskrat	Conant Creek	32-094-03cab01[2]	Wagon Bed Formation	Twb	1116321.682	1157929.68
Muskrat	Conant Creek	33-094-23dbd01[2]	Nugget Sandstone	JTRn	1118392.312	1173041.32
Muskrat	Conant Creek	33-094-26ddb01[2]	Chugwater Formation or Group	TRc	1119263.028	1167171.41
Muskrat	Conant Creek	33-094-27adb01[2]	Mowry Shale	Kmr	1112727.938	1169601.723
Muskrat	Conant Creek	Cogswell Spring[3]	Wagon Bed Formation	Twb	1109418.628	1158285.645
Muskrat	Conant Creek	Keg Spring[3]	Frontier Formation	Kf	1106140.723	1169035.336
Muskrat	Conant Creek	LAT-LONG 4243441075953[2]	White River Formation	Twr	1133572.387	1140931.141
Muskrat	Conant Creek	Peralta Spring[3]	Wind River Formation	Twdr	1166814.336	1183059.348
Muskrat	Conant Creek	Pipe Spring[3]	Cloverly Formation or Inyan Kara Group and Morrison Formation	KJ	1123206.883	1167053.039
Muskrat	Conant Creek	T32nR93wS07[1]	Chugwater and Dinwoody Formations	TRcd	1134389.567	1154071.598
Muskrat	Conant Creek	T32nR93wS14A[1]	Wagon Bed Formation	Twb	1153737.448	1147918.001
Muskrat	Conant Creek	T32nR93wS14B[1]	Wagon Bed Formation	Twb	1151610.686	1147717.147
Muskrat	Conant Creek	T32nR93wS18[1]	Wagon Bed Formation	Twb	1131212.546	1148826.989
Muskrat	Conant Creek	T32nR93wS22[1]	White River Formation	Twr	1146647.565	1143955.434
Muskrat	Conant Creek	T32nR94wS03[1]	Chugwater and Dinwoody Formations	TRcd	1119445.569	1156402.929
Muskrat	Conant Creek	T33nR93wS32[1]	Mowry and Thermopolis Shales	Kmt	1132396.384	1163625.99
Muskrat	Conant Creek	T33nR94wS14A[1]	Frontier Formation	Kf	1119956.508	1178170.189
Muskrat	Conant Creek	T33nR94wS14B[1]	Frontier Formation	Kf	1119194.517	1177225.124
Muskrat	Conant Creek	T33nR94wS25[1]	Cloverly Formation or Inyan Kara Group and Morrison Formation	KJ	1123743.425	1166442.547
Muskrat	Conant Creek	T33nR94wS36[1]	Chugwater and Dinwoody Formations	TRcd	1124870.061	1161024.339

Notes:
Springs that have been named on the USGS quads[(3)] (NGS 2011) or as associated with USGS water quality datasets[(2)] (USGS 2015) are listed with their given name.

Springs that are simply referred to as "spring" on the USGS quads (NGS 2011) have been given a name based on their location in the PLSS system[(1)] (i.e. township, range, section). For PLSS sections that contain more than one spring the given spring names include an alpha suffix (i.e. "A", "B"…) to distinguish between them.

The northing (Y) and easting (X) coordinates area presented in NAD_1983_StatePlane_Wyoming_East_Central_FIPS_4902_Feet WKID: 3737 Authority: EPSG.

4.1.2.2 Reservoirs

The Lower Poison Creek watershed contains four named reservoirs: Dinty Moore, Graham, Ocla, and Robinson reservoirs. The Upper Poison Creek watershed contains 12 named reservoirs: Adobe, Burke, Dead Horse, Frenchie, Garrison, Highland, Iron Springs Reservoir, Medicine Springs, Neal, Pine Tree, Seventy-One, and Wolton reservoirs. Highland, Iron Springs, Medicine Springs, and Wolton reservoirs appear to be decommissioned from aerial photo inspection. The locations of the named reservoirs are shown on Figure 6.

4.1.2.3 USGS Springs

In the Lower Wind subbasin, the Upper Poison Creek watershed contains three named springs and eight unnamed springs. A summary of the Lower Wind subbasin spring data is presented in Table 2 and the locations of springs in the Lower Wind subbasin are shown on Figure 6.

4.1.3 Muskrat Subbasin

The Muskrat subbasin encompasses approximately 735 square miles in the southern portion of the analysis area (Figure 4). Its drainage network comprises three named watersheds (HUC 10 level): Lower Muskrat, Conant, and Upper Muskrat creek watersheds, from west to east (Figures 6).

4.1.3.1 Drainages

The Lower Muskrat Creek watershed is approximately 203 square miles in areal extent and contains three named drainages: Dry Cheyenne, Oil Springs, and Muskrat creeks (Figure 6). The Upper Muskrat Creek watershed is approximately 299 square miles in areal extent and contains nine named drainages: Coyote Creek, Fish Draw, Fraser Draw, Indian Grove Creek, Mahoney Draw, Murphy Draw, Spring Creek, Willow Reid Draw, and Muskrat Creek (Figure 6). The main channel of Muskrat Creek is approximately 74 miles long from its headwaters near Beaver Divide to its terminus at Boysen Reservoir. Muskrat Creek has an average gradient of -0.50 percent.

The Conant Creek watershed is approximately 233 square miles in areal extent and contains six named drainages: Horseshoe, Logan Gulch, Moone, Rock, Signor Draw, and Conant creeks (Figure 6). The main channel of Conant Creek is approximately 31 miles long from its headwaters near Beaver Divide to its junction with Muskrat Creek. Conant Creek has an average gradient of -0.89 percent.

4.1.3.2 Reservoirs

The Lower Muskrat watershed contains five named reservoirs and lakes: Allard, Brody, Deadman, and Fuller reservoirs; and Campbell Lake. The Upper Muskrat watershed contains seven named reservoirs: Barber, Cameron Spring, Fraser, Leitch, Mahoney, Reid, and Willow Springs reservoirs. Willow Springs Reservoir appears to be decommissioned from aerial photo inspection. The locations of the named reservoirs are shown on Figure 6.

The Conant Creek watershed contains 13 named reservoirs: Chimney Rock, Double Butte, East Horseshoe, Findlay, Homestead Flat, Logan Junction, Logan, North Logan, Rongis, Sherlock, Signor, Sucker Reservoir, and Upper Signor reservoirs. The locations of the named reservoirs are shown on Figure 6.

4.1.3.3 USGS Springs

In the Muskrat subbasin, the Upper Muskrat Creek watershed contains five named springs. The Conant Creek watershed contains nine named springs and 11 unnamed springs. A summary of the Muskrat subbasin spring data is presented on Table 2 and the locations of springs in the Muskrat subbasin are shown on Figure 6.

4.1.4 Boysen Reservoir

Boysen Reservoir has approximately 76 miles of shoreline and is about 20 miles long and 5.5 miles wide at its widest point (Wyoming State Parks 2015). The Boysen Reservoir Dam is a 220-foot- high, zoned-earth-fill structure built by USBR between 1947 and 1952. Boysen Reservoir began filling in March 1952 and dams the Wind River approximately 17 miles south of Thermopolis, Wyoming (Figures 1 and 4). Design discharge through the spillway is 25,000 cubic feet per second (cfs) at a water surface elevation of 4,725 feet above mean sea level. The power-generating outlet works discharge capacity is 1,300 cfs at the same water surface elevation. Boysen Reservoir has a total controlled storage capacity of 802,000 acre-feet at a water surface elevation of 4,725 feet above mean sea level (USBR 2015). The drainage area contributing to Boysen Reservoir is approximately 7,031 square miles.

4.2 Streamflows

The majority of the streams in the analysis area are classified as intermittent or ephemeral. Several of the upper reaches of streams in the Badwater subbasin are classified as perennial (Figure 5). Major tributaries to Badwater Creek in the Production Area include Alkali, Sand, and Bridger creeks (perennial). Deer Creek (Lower Wind subbasin) is the only perennial stream (Figure 6) that feeds Poison Creek. Poison Creek itself is perennial below the discharge from the Shoshoni Wastewater Treatment Plant. In the Muskrat subbasin, only a short reach of Conant Creek and some of its tributaries are classified as perennial (USDA 2015)

To support ranching operations in the analysis area, diversion ditches divert water from streams to fill small reservoirs and for direct irrigation of hay fields. There are a number of small reservoirs in the analysis area, many of which are used as stock ponds. A number of these are located in streambeds and fill up during runoff events from rainfall. Seasonally, diversions occur during the growing season in spring and summer, as well as during the fall, in order to fill the reservoirs. Intermittent flow occurs where irrigation water returns to streams.

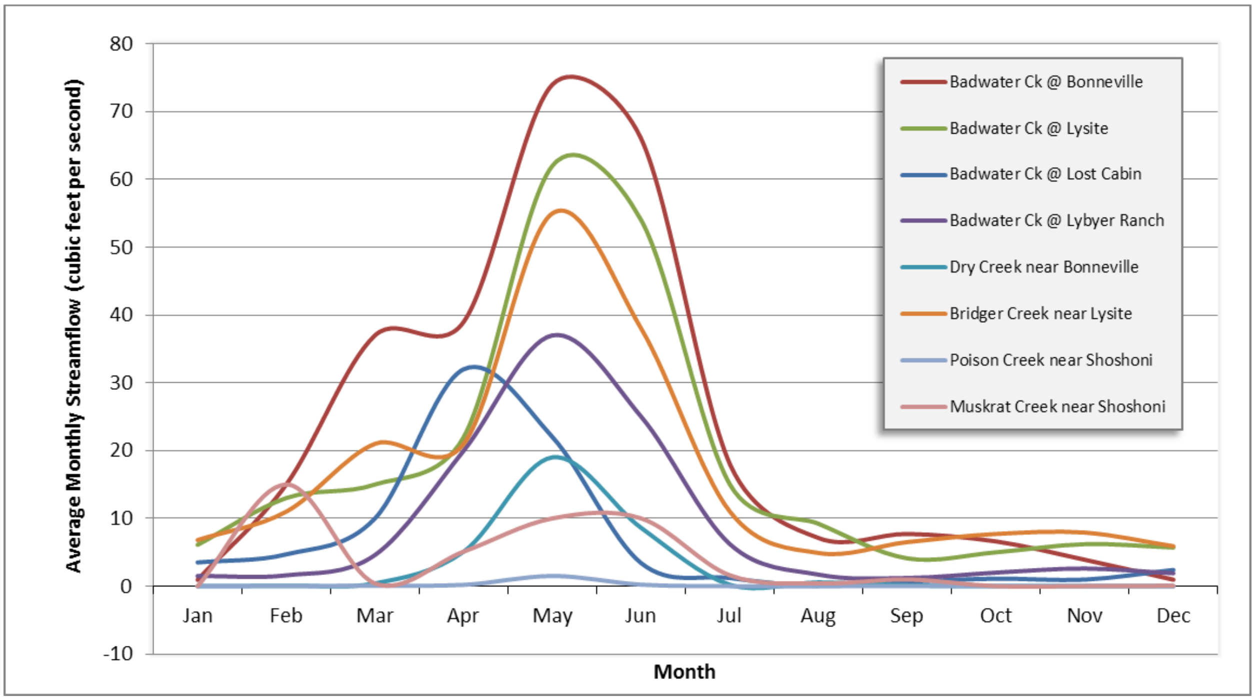
Streamflow is measured at ten USGS Flow/Water Quality Stations (USGS gaging stations) in or near the analysis area (USGS 2015):

- Badwater Creek at Bonneville, Wyoming (6257000)
- Badwater Creek at Lybyer Ranch near Lost Cabin, Wyoming (6256000)
- Badwater Creek at Lost Cabin, Wyoming (6256500)
- Badwater Creek at Lysite, Wyoming (6256650)
- Bridger Creek near Lysite, Wyoming (6256800)
- Dry Creek near Bonneville, Wyoming (6256900)
- Poison Creek near Shoshoni, Wyoming (6255500)
- Muskrat Creek near Shoshoni, Wyoming (6239000)
- Wind River above Boysen Reservoir near Shoshoni, Wyoming (6236100)
- Wind River below Boysen Reservoir, Wyoming (6259000)

The locations of the USGS gaging stations are shown on Figure 5.

Average monthly streamflow data from eight USGS gaging stations in the analysis area are graphically illustrated in Figure 7. Average monthly flows for the period of record, maximum instantaneous peak flow, and date of peak flow data from the 10 USGS gaging stations in or near the analysis area are summarized in Table 3. Streamflow data for the Wind River above and below Boysen Reservoir are discussed in Section 4.2.1, *Boysen Reservoir: Inflows from the Analysis Area and Outflows*).

Figure 7. Average Monthly Streamflows (cfs) in the Analysis Area



Source: USGS 2015

Table 3. Streamflow Data

USGS Gage Number	Name	Period of Record	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Inst. Peak Flow	Peak Flow Date
6257000	Badwater Creek at Bonneville, WY	May 1, 1947 to Sept. 30, 1973	0.93	15	37	39	74	66	18	7.1	7.7	6.6	3.9	0.95	18,600	24-Jul-23
6256650	Badwater Creek at Lysite, WY	Nov. 1, 1965 to Sept. 30, 1973	6.1	13	15	22	62	54	15	9.2	4.1	5	6.2	5.7	6,240	8-Jun-68
6256500	Badwater Creek at Lost Cabin WY	Sept. 1, 1945 to Sept. 30, 1948	3.5	4.7	10	32	22	3.4	1.2	0.04	0.66	1.1	0.96	2.4	no data	no data
6256000	Badwater Creek at Lybyer Ranch, near Lost Cabin, WY	Sept. 1, 1945 to Sept. 30, 1948	1.5	1.6	4.6	20	37	25	6.2	1.7	1.2	2	2.6	1.9	1,060	16-Jul-68
6256900	Dry Creek near Bonneville, WY	Oct. 1, 1965 to Sept. 30, 1980	0	0.08	0.41	5.1	19	8.6	0.22	0.56	0.12	0.02	0.01	0	1,650	17-Jun-67
6256800	Bridger Creek near Lysite, WY	Nov. 1, 1965 to Sept. 30, 1973	6.8	11	21	21	55	38	11	4.9	6.5	7.7	7.9	5.9	880	9-Jun-68
6255500	Poison Creek near Shoshoni, WY	Oct. 1, 1952 to Dec. 31, 1953	no data	0	0.07	0.2	1.5	0.23	0	0	0	0	0	0	2,950	5-Jun-67
6239000	Muskrat Creek near Shoshoni, WY	July 1, 1950 to Sept. 30, 1973	0	15	0.4	5.1	10	10	1.6	0.39	0.99	0	0	0.05	13,300	10-Feb-62
6236100	Wind River ab Boysen Reservoir, near Shoshoni, WY	May 1, 1990 to Apr. 30, 2013	494	521	631	568	1,540	4,150	1,940	531	469	663	716	544	19,200	9-Jun-10
6259000	Wind River below Boysen Reservoir, WY	June 1, 1951 to Sept. 30, 2013	997	966	1,040	1,160	1,500	2,340	2,400	1,460	1,220	1,080	1,060	1,050	13,500	7-Jul-67

Source: USGS 2015
All flows are cubic feet per second (cfs).
Monthly values represent average monthly flows over the period of record (variable periods of record).

While average monthly streamflows in Badwater, Bridger, Poison, and Alkali creeks are very low, ranging from dry to 74 cfs, summer thunderstorms create short-term flows of much larger magnitudes. Over the period of record (various for the stations), peak flows have ranged from 880 cfs at Bridger Creek near Lysite, Wyoming (6256800) to 19,200 cfs at Wind River at Boysen Reservoir, near Shoshoni, Wyoming (6236100) (Table 3). Large summer floods combined with the downstream decrease in streamflows create dry streambeds with large accumulations of sandy sediments (Photo 2).

Photo 2. Dry Creek Bed in Badwater Creek, North of Shoshoni, Wyoming

The creek bed in Badwater Creek near its mouth is dry and full of deposited sediment. Photo taken August 27, 2013

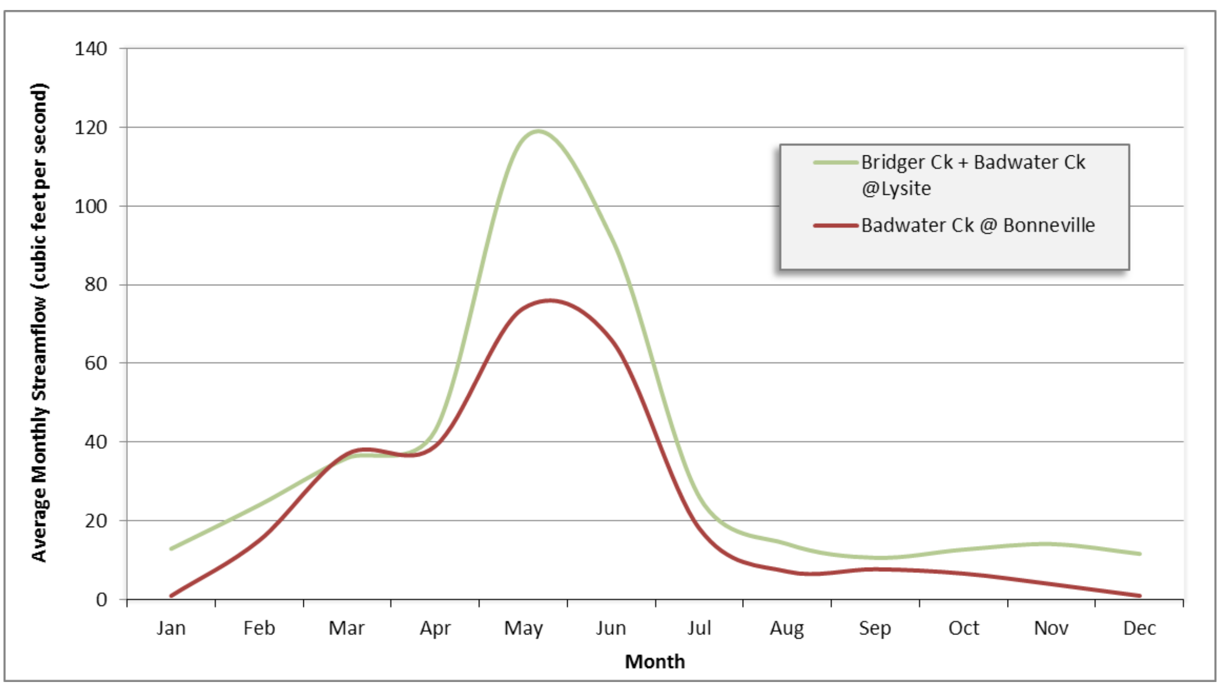
Alkali Creek and its tributaries have received discharge water from oil and gas drilling operations since 1978. Prior to oil and gas production, Alkali Creek and its tributaries were ephemeral streams, flowing only in response to rainfall or snowmelt (Figure 5). Prior to the addition of discharge water, the naturally occurring moisture regime in the channel bottoms generally supported a relatively dense grass community. This vegetation coverage across the floodplain and channel increased the channel and floodplain roughness and flow resistance, reduced near-bank shear stress, and reduced flow velocity, thereby reducing erosion potential. Additionally, a well-established root system associated with the vegetation mechanically strengthened and reinforced the channel soils and the aboveground vegetative growth flattened during storm flow events, creating a protective boundary between active flows and the underlying soils (Oasis Environmental 2010).

Discharge of produced water from oil and gas production has created perennial flowing tributaries to Alkali Creek and perennial reaches in Alkali Creek. Discharge water supports wetlands, wildlife, and agriculture. Perennial flows in those formerly ephemeral drainages has caused disturbance of the drainage beds and drowning of drainage-way vegetation, which, in turn, has led to accelerated erosion. In addition, continuously saturated soils have less strength to withstand scour and erosion, and increased freeze/thaw activity increases erosion. In the small ephemeral channels below the outfalls, the dominant fluvial process has been largely degradational, with lesser areas of deposition and aggradation distributed throughout the reaches. In Alkali Creek both degradation (scour) and aggradation (deposition) processes are occurring. Over time, these processes have increased down-cutting in tributary channels, creating site conditions unfavorable to livestock movement, grazing and watering, and increased sediment loading in Alkali Creek (Oasis Environmental 2010). Aethon conducts ongoing channel stability, erosion, and streamflow monitoring at several locations in Alkali Creek (Encana 2011; Lowham Walsh LLC 2018) (Figure 16) in accordance with Wyoming DEQ WYPDES Discharge Permit WY0002062 (Wyoming DEQ 2015). Some upper reaches of Alkali Creek have springs that create intermittent to perennial pools which contain fish (Conrad 2015).

4.2.1 Boysen Reservoir: Inflows from Analysis Area and Outflow

Poison and Badwater creeks flow westward through the Production Area and drain into Boysen Reservoir (Figure 4). Muskrat Creek flows northwestward, south of the Production Area, and drains into Boysen Reservoir (Figure 4). Due to diversions, evaporation, and infiltration, only a little water reaches Boysen Reservoir from Badwater, Poison, or Muskrat creeks. This is illustrated in Figure 8, which shows that the combined flows in Badwater and Bridger creeks above Lysite (closer to the source of Badwater Creek) are greater than the flow in Badwater Creek near Bonneville (near the mouth of Badwater Creek).

Figure 8. Upstream (Near Lysite) and Downstream (Near Bonneville) Flows in Badwater Creek



Source: USGS 2015

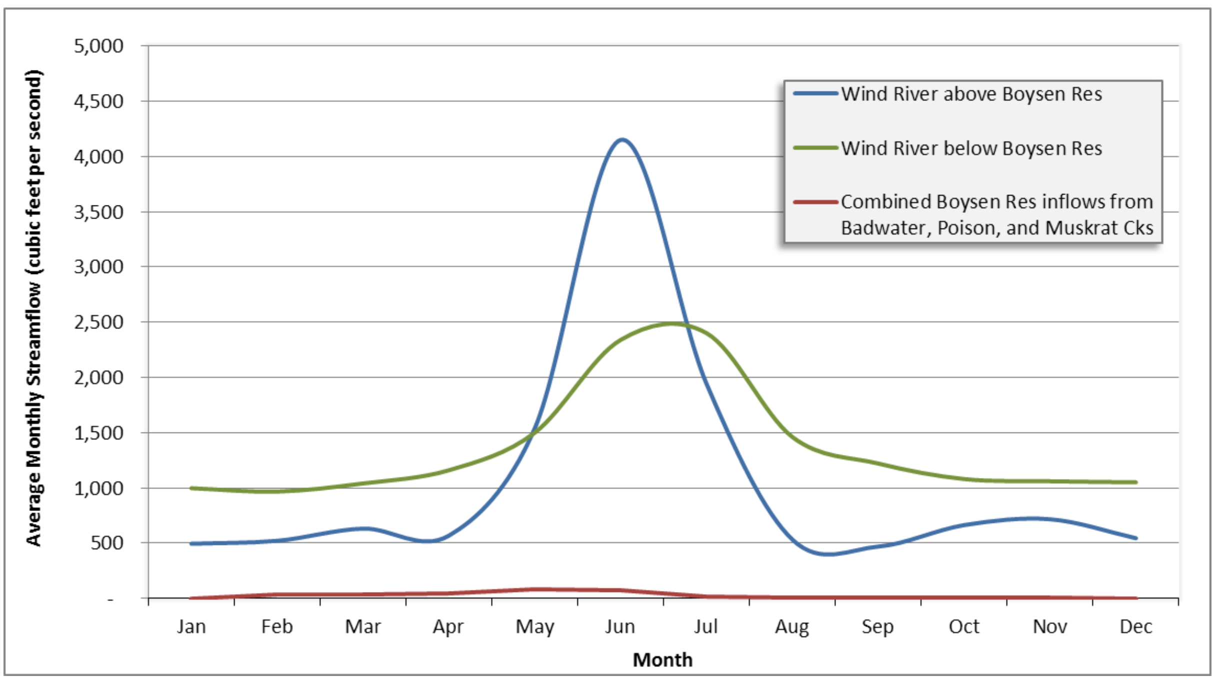
Notes: Data for Badwater and Bridger creeks were added mathematically, in order to compare combined flows near Lysite to combined flow near Bonneville, as no combined flow data below the confluence exist. However, data for flows near Lysite are for a different period of record than flows near Bonneville; thus, no exact statistical comparison can be made; however, qualitative conclusions are valid.

Flows into and out of Boysen Reservoir are measured at two USGS gaging stations:

- The Wind River above Boysen Reservoir near Shoshoni, Wyoming (6236100) gaging station is located upstream of Boysen Reservoir and measures inflow from the Wind River into Boysen Reservoir.
- The Wind River below Boysen Reservoir, Wyoming (6259000) gaging station measures flow in the Wind River downstream from Boysen Reservoir.

The monthly average streamflows and instantaneous maximum flows for these Wind River gaging stations are shown in Table 3. Over the period of record (variable for these sites), maximum peak flows were 19,200 cfs above Boysen Reservoir (6236100) and 13,500 cfs below Boysen Reservoir (6259000). Figure 9 illustrates that the vast majority of flow into and out of Boysen Reservoir is contributed by the Wind River.

Figure 9. Average Monthly Streamflows Into and Out of Boysen Reservoir



Source: USGS 2015

Notes: Data for Badwater, Poison, and Muskrat creek drainages were added mathematically, in order to compare the different sources of inflow to Boysen Reservoir. However, data for each source are for different periods of record; thus, no exact statistical comparison can be made; however, qualitative conclusions are valid.

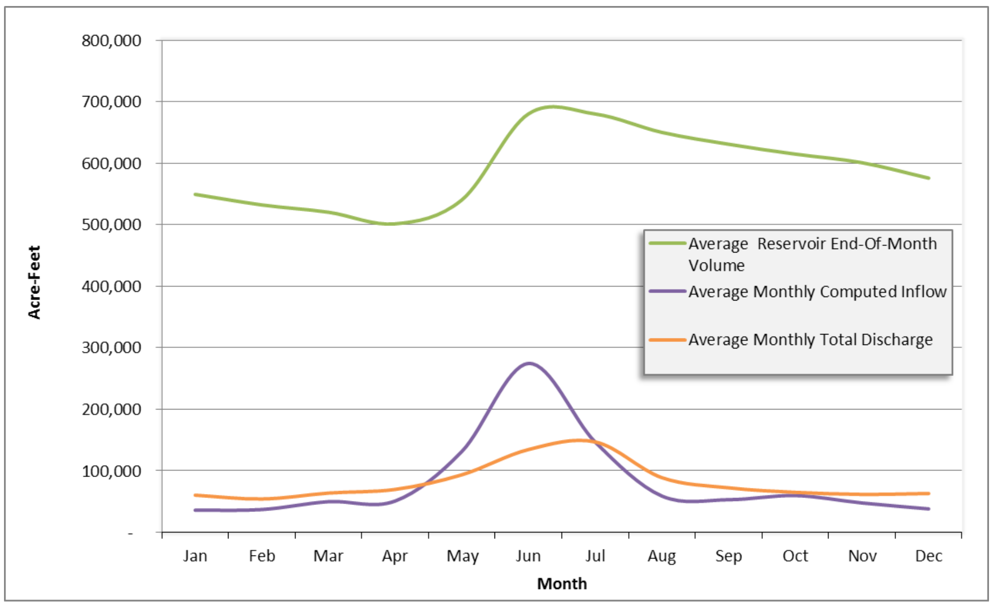
USBR actively manages the volume of water in Boysen Reservoir to meet assigned allocations for conservation, use, and flood control (USBR 2015). The Boysen Reservoir average monthly end-of-month volume (acre-feet), average monthly total discharge (acre-feet), and computed average monthly total inflows (acre-feet) are shown in Table 4 and Figure 10. The complete period of record (March 1952 through December 2014) monthly datasets are presented in Attachment A.

Table 4. Flow and Volume Data for Boysen Reservoir

Parameter	Period of Record	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Inst. Max	Date	Inst. Min1	Date
Average Reservoir End-Of-Month Volume	Mar. 1952 to Dec. 2014	549,436 acre-feet	532,239 acre-feet	520,337 acre-feet	501,485 acre-feet	540,463 acre-feet	680,350 acre-feet	680,054 acre-feet	650,152 acre-feet	630,854 acre-feet	614,853 acre-feet	00,890 acre-feet	575,820 acre-feet	922,406 acre-feet	6-Jul-67	235,737 acre-feet	22-Sep-02
Average Monthly Computed Inflow	Mar. 1952 to Dec. 2014	36,029 acre-feet	37,049 acre-feet	49,933 acre-feet	50,986 acre-feet	131,553 acre-feet	274,511 acre-feet	146,726 acre-feet	59,008 acre-feet	53,072 acre-feet	59,824 acre-feet	47,746 acre-feet	38,139 acre-feet	--	--	--	--
Average Monthly Total Discharge	Mar. 1952 to Dec. 2014	60,450 acre-feet	54,210 acre-feet	63,877 acre-feet	69,865 acre-feet	93,560 acre-feet	134,707 acre-feet	147,024 acre-feet	88,883 acre-feet	72,397 acre-feet	65,009 acre-feet	61,714 acre-feet	63,204 acre-feet	--	--	--	--

Source: USBR 2015
[1]Instantaneous minimum (Inst. Min.) excludes the initial reservoir fill-up period in 1952.

Figure 10. Average Monthly Flow and Volume Data for Boysen Reservoir



Source: USBR 2015
Based on period of record March 1952 to December 2014 (Table 4).

4.3 Surface Water Quality

4.3.1 Sediment and Total Dissolved Solids Loading in Analysis Area

As surface water in the Badwater, Lower Wind, and Muskrat subbasins flows downstream, natural erosional processes increase sediment and total dissolved solid (TDS) loads and, therefore, influence downstream water quality (Wyoming DEQ 2012). Discharges from oil and gas development and irrigation return flow also affect water quality. Most of the analysis area has thin soils derived from highly erodible, saline, alkaline, and/or phosphate-rich geologic materials (Wyoming DEQ 2012). Water flow in Alkali and Badwater creeks downstream of Alkali Creek is dominated by oil and gas production discharge water. Water quality is thus influenced by increased erosion and sediment transport from the discharge water and the original water quality of the discharge water. Discharge water quantity and quality is discussed in Section 5.5, *Surface Water Discharge*. All streams in the analysis area carry a high sediment load when they are flowing, with suspended sediment concentrations frequently exceeding 20 grams per liter (g/L) near the mouth of streams (USGS 2015).

4.3.2 Wyoming Department of Environmental Quality Classified Waters

Based on water quality and flows, Wyoming DEQ classifies streams and reservoirs in Wyoming according to different existing and designated uses, as follows (Wyoming DEQ 2013a):

- Class 1: Outstanding waters—water quality, physical, and biological integrity that existed at the time of designation will be maintained and protected. Uses include drinking water, cold water game fish, non-game fish, fish consumption, other aquatic life, recreation, wildlife, agriculture, industry, and scenic value
- Class 2AB: Drinking water, cold water game fish, non-game fish, fish consumption, other aquatic life, recreation, wildlife, agriculture, industry, scenic value
- Class 2C: Non-game fish, fish consumption, other aquatic life, recreation, wildlife, agriculture, industry, scenic value
- Class 3B: Other aquatic life, recreation, wildlife, agriculture, industry, scenic value
- Class 4B: Intermittent and ephemeral, lacking the hydrologic potential to normally support and sustain aquatic life

Waterbodies are classified according to designated uses even if current conditions may not allow these uses. All streams in the analysis area are classified as 2AB, 2C, 3B, or 4B (Table 5). The Wind River below Boysen Reservoir is classified as Class 1 water.

Table 5. Wyoming Use Classification for Streams and Reservoirs in the Analysis Area

Class 1	Class 2AB	Class 2C	Class 3B	Class 4B
• Wind River Below Boysen Dam	• Badwater Creek • Boysen Reservoir • Bridger Creek • Clear Creek • Hoodoo Creek • Poison Creek Below Shoshone Outfall • Sioux Creek • West Fork Dry Creek • Wind River (upstream of Boysen Reservoir)	• Conant Creek • Muskrat Creek • Poison Creek Above Shoshone Outfall	• Alkali Creek • Canyon Creek • Cottonwood Creek • Coyote Creek • Deer Creek • Dolus Creek • Dry Cheyenne Creek • Dry Creek • Dry Fork Badwater Creek • Dry Gulch • East Canyon Creek • East Fork Dry Creek • E-K Creek • Fish Draw • Fraser Draw • Fraser Reservoir • Frenchie Draw • Fuller Reservoir • Horseshoe Creek • Logan Creek • Lysite Creek • Mahoney Draw • Murphy Draw • Oil Springs Creek • Red Creek • Reservoir Creek • Rongis Reservoir • South Fork Badwater Creek • South Fork Sand Creek • Sand Creek • Schoening Creek • Signor Draw • Snyder Creek • West Canyon Creek	• All Unnamed Tributaries to Sand Creek • Sand Creek • Willow Springs Draw

Source: Wyoming DEQ 2013a
Note: Water bodies are classified based on "designated uses" even if current conditions may not allow these uses.

Poison Creek receives discharge from the Shoshoni Municipal Water Treatment Plant at the Shoshoni Outfall, creating a perennially flowing stream (Figure 5), and is considered impaired downstream of the outfall. *Escherichia coli* (E. coli) bacteria concentrations exceed Wyoming DEQ water quality limits below the outfall; therefore, Poison Creek is not suitable for wading, swimming, or other water-contact recreation (Wyoming DEQ 2012). Although the reach of Poison Creek below the Shoshoni Municipal Water Treatment Plant is impaired, it is still classified as Class 2AB, which is a higher classification than the portion of Poison Creek that is upstream of the plant, which is classified as Class 2C.

4.3.3 Numerical Water Quality Criteria

Wyoming DEQ has established numerical water quality criteria for the protection of human health. In all Class 1, 2AB, and 2A waters, the *Human Health Consumption of Fish and Drinking Water* standard values listed in Tables 6 and 7 must not be exceeded. In all Class 2B, 2C, and 2D waters, the *Human Health Consumption of Fish* (consumption of aquatic organisms) standard values must not be exceeded (Section 18, Ref 3194). The Wyoming DEQ *Water Quality Rules and Regulations*, Chapter 1, Quality Standards for Wyoming Surface Water (Wyoming DEQ 2013b) document is attached as Attachment B.

Wyoming DEQ has also established numerical water quality criteria for the protection of aquatic life. The toxicity of ammonia varies with pH and temperature and the applicable limitations are included in Attachment B. The numeric ammonia criteria apply to all Class 1, 2AB, 2A, 2B, and 2C waters (Section 21, Wyoming DEQ 2013b).

Specific numeric standards for other parameters are listed under *Aquatic Life Acute Value* and *Aquatic Life Chronic Value* in Tables 6 and 7. These standards apply to all Class 1, 2, and 3 waters. For these pollutants, the chronic value (4-day average concentration) and the acute value (1-hour average concentration) must not be exceeded more than once every 3 years (Section 21, Wyoming DEQ 2013b).

For both human health and aquatic life standards, Wyoming DEQ recognizes that, in certain waters, the criteria listed in Tables 6 and 7 may not be appropriate due to unique physical or chemical conditions. In such cases, the standard values may be established using the site-specific procedures as approved by Wyoming DEQ. Also, for pollutants not listed in Tables 6 and 7, maximum allowable concentrations on Class 1, 2 and 3 waters must be determined through bioassay procedures approved by Wyoming DEQ (Sections 18 and 21, Wyoming DEQ 2013b).

Wyoming DEQ has established ambient water temperature criteria for surface water. For Class, 1, 2, and 3 waters, human activities may not change ambient water temperatures to a degree that would have harmful acute or chronic effects on aquatic wildlife or that would not support existing or designated uses. When ambient temperatures are above 60 degrees Fahrenheit (15.6 degrees Celsius) in all Class 1, 2AB, and 2B waters, which support coldwater fish, pollution attributable to human activities must not result in an increase of more than 2 degrees Fahrenheit (1.1 degree Celsius) in existing temperatures. When ambient temperatures are above 60 degrees Fahrenheit (15.6 degrees Celsius) in all Class 1, 2AB, 2B, and 2C waters, which support warm-water fish, pollution attributable to human activities must not result in an increase of more than 4 degrees Fahrenheit (2.2 degrees Celsius) in existing temperatures (Section 21, Wyoming DEQ 2013b).

Table 6. Wyoming DEQ Surface Water Quality Criteria –Priority Pollutants

Priority Pollutant[1]	Aquatic Life		Human Health Consumption of	
	Acute Value (µg/L)	Chronic Value (µg/L)	Fish and Drinking Water[2] (µg/L)	Fish[7] (µg/L)
Aldrin	1.5[16]		0.000049[3]	0.000050[3]
Dieldrin	0.24	0.056	0.000052[3]	0.000054[3]
Chlordane	1.2[16]	0.0043	0.00080[3]	0.00081[3]
4,4'-DDT	0.55[16]	0.001	0.00022[3]	0.00022[3]
alpha-Endosulfan	0.11[16]	0.056	62	89
Endrin	0.086	0.036	0.059	0.060
Heptachlor	0.26[16]	0.0038	0.000079[3]	0.000079[3]
Heptachlor epoxide	0.26[16]	0.0038	0.000039[3]	0.000039[3]
Polychlorinated biphenyls		0.014[12]	0.000064[3][12]	0.000064[3][12]
Toxaphene	0.73	0.0002	0.00028[3]	0.00028[3]
Arsenic	340	150	10[3][8]	10[3][8]
Beryllium			4[8]	
Cadmium	2.0[4]	0.25[4]	5[8]	
Chromium (III)	569.8[4]	74.1[4]	100[8]	(total)
Chromium (VI)	16	11	100[8]	(total)
Copper	13.4[4]	9[4]	1000[6]	
Cyanide (free)	22	5.2	140[5]	140[5]
Lead	64.6[4]	2.5[4]	15[8]	
Mercury	1.4	0.77	0.050	0.051
Nickel	468.2[4]	52.0[4]	610	4,600
Selenium	20[9]	5[9]	50[8]	4,200
Silver	1.7[4][16]		100[10]	
Zinc	117.2[4]	118.1[4]	5,000[6]	26,000

Source: Wyoming DEQ 2013b

Notes: See additional footnotes at end of Table 7.

"Priority pollutants" means those substances or combination of substances that are listed by the Environmental Protection Agency (EPA) under Section 307(a) of the Clean Water Act.

Eighty-two Priority Pollutants were removed from this list, as they are not applicable to the water quality datasets analyzed in this report. For a full list of Priority Pollutants see Attachment B.

µg/L= micrograms per liter

Table 7. Wyoming DEQ Surface Water Criteria - Non-Priority Pollutants

Non-Priority Pollutant(1)	Aquatic Life		Human Health Consumption of Fish and Drinking Water(2) (µg/L)
	Acute Value (µg/L)	Chronic Value (µg/L)	
Alachlor			2(8)
Aluminum (pH 6.5-9.0 only)	750	87(14)	
Ammonia	See Attachment B		
Atrazine			3(8)
Barium			2,000(8)
Carbofuran			40(8)
Chloride	860,000(15)	230,000(15)	
Chlorpyrifos	0.083	0.041	
Chlorophenoxy herbicide (2,4-D)			70(8)
Diazinon	0.17	0.17	
Dissolved Oxygen		See Attachment B	
Fluoride			2000(10)
Iron		1000(11)	300(10)
Malathion		0.1	
Manganese	3110(4)(11)	1462(4)(11)	50(10)
Methoxychlor		0.03	40(8)
Mirex		0.001	
Nitrite (as N)			1000(8)
Nitrates (as N)			10000(8)
Nitrite+Nitrate (both as N)			10000(8)
pH		6.5-9.0	
Simazine			4(8)

Source: Wyoming DEQ 2013b
Non-priority pollutant means any substance or combination of substances other than those listed by EPA under Section 307(a) of the Clean Water Act.
Thirty-eight Non-Priority Pollutants were removed from this list, as they are not applicable to the water quality datasets analyzed in this report. For a full list of Non-Priority Pollutants, see Attachment B.
µg/L= micrograms per liter

Additional Notes for Table 6 and Table 7:

(1) Except for the aquatic life values for metals and where otherwise indicated, the values given in Tables 6 and 7 refer to the total recoverable (dissolved plus suspended) amount of each substance. For the aquatic life values for metals, the values refer to dissolved amount.

(2) Except where otherwise indicated, these values are based on EPA Section 304(a) criteria recommendations assuming consumption of 2 liters of water and 17.5 grams of aquatic organisms per day.

(3) Except for arsenic, the substance is classified as a carcinogen with the value based on an incremental risk of one additional instance of cancer in one million persons. Arsenic is classified as a carcinogen; however, the value is not based on an additional 1:1,000,000 cancer risk.

(4) Hardness dependent criterion. Value given is an example only and is based on a CaCO3 hardness of 100 mg/L. Criteria for hardness concentrations other than 100 mg/L as CaCO3 must be calculated using the formulas in Attachment B.

(5) pH dependent criterion. Value given is based on a CaCO3 hardness of 100 mg/L. Other values for CaCO3 must be calculated using formulas in Attachment B.

(6) Criterion expressed as total cyanide, even though the method used to derive the criterion is based on free cyanide. If a substantial fraction of the cyanide present in a waterbody is present in a complexed form (e.g. Fe4[Fe(CN)6]3), this criterion may be overly conservative.

(7) Criterion is based on organoleptic (taste and odor) effects and is more stringent than if based solely on toxic or carcinogenic effects.

(8) EPA Section 304(a) human health criteria recommendation assuming consumption of contaminated aquatic organisms at a rate of 17.5 grams per day.

(9) Criterion is based on an EPA drinking water standard (maximum contaminant level or MCL).

(10) This value is expressed in terms of total recoverable metal in the water column. It is scientifically acceptable to use a conversion factor (0.996 for the acute and 0.922 for the chronic) to convert this number to a value that is expressed in terms of a dissolved metal. Using these conversion factors, the aquatic life acute value for selenium is 19.92 µg/L as a dissolved metal and the aquatic life chronic value for selenium is 4.61 µg/L as a dissolved metal.

(11) Criterion is based on Safe Drinking Water Act secondary standards and is intended to prevent undesirable cosmetic or aesthetic effects. Value represents the dissolved amount of each substance rather than the total amount. Criterion only applies where drinking water is an actual use.

(12) Value is based on the dissolved amount which is the amount that will pass through a 0.45-µm membrane filter prior to acidification to pH 1.5-2.0 with nitric acid.

(13) This criterion applies to total PCBs (i.e. the sum of all congener or all isomer or homolog or Aroclor analyses).

(14) The 87 mg/L criterion for aluminum is based on information showing chronic effects on brook trout and striped bass. The 87 mg/L criterion will apply except where the receiving water after mixing has a pH greater than or equal to 7.0 and a hardness (CaCO3) greater than or equal to 50 mg/L. Where the receiving stream after mixing has a pH greater than or equal to 7.0 and hardness (as CaCO3) greater than or equal to 50 mg/L, the 750 mg/L acute criterion will apply. In situations where the 87 mg/L chronic criterion applies, a discharger may request development of and provide the basis for a site-specific criterion based on a water-effect ratio.

(15) Criterion applies on Class 1, 2AB and 2B and 2C waters only.

4.3.4 Surface Water Quality Data

4.3.4.1 Streams and Boysen Reservoir

USGS has collected surface water quality samples at 12 different stream locations in the analysis area (Table 8). These locations have been divided into five groups based on physical location: Wind River above Boysen Reservoir, Wind River below Boysen Reservoir, Muskrat Creek near Shoshoni, Badwater subbasin, and the Lower Poison Creek watershed. The locations of the USGS Flow Stations (stream sampling sites) are shown on Figure 4. The complete surface water quality data are presented in Attachment C.

Six additional stream locations with associated water quality data are found in the U.S. Environmental Protection Agency (EPA) STORET database (EPA 2015) (Table 8): G-48 and 197, on the Wind River above Boysen Reservoir; G-53, 205, and 1048, below the Boysen Dam; and 1049, at the Wedding of the Waters site, just south of Thermopolis, Wyoming. The locations of the STORET water quality stations are shown on Figure 4. Unfortunately, the water quality data in the STORET datasets for Wind River above Boysen (G-48 and 197), Wind River Canyon (G-53, 205, 1048, 1049), and Boysen Reservoir (NLA06608-0950 and WB163) have been determined unusable due to errors in reporting units and were not included in the analyses presented in this report.

Water quality data for Boysen Reservoir were obtained via the EPA STORET database from three stations: Boysen Reservoir (Station 1011), Boysen Reservoir (Station NLA06608-0950), and WB163 Wind River – Boysen (Station WB163) (EPA 2015) (Table 8). The data were collected by the Wind River Environmental Quality Commission, the Wyoming DEQ Watershed Program, and the EPA National Aquatic Resources Survey. However, after careful review, the data from station NLA06608-950 and WB163 were deemed unusable due to errors in reporting units and were not included in the analysis presented in this report.

Table 8. Surface Water Quality Data Stations

Station Type	Station Name	Station ID	Period of Record	Comments
Wind River above Boysen Reservoir				
USGS	Wind River above Boysen Reservoir, WY	6236100	1/4/1973 to 12/16/2014	Lab and Field Data
EPA STORET	Wind River above Boysen	G-48	8/21/2005 to 11/30/2005	Data unusable
EPA STORET	Wind River above Boysen	197	8/21/2005 to 11/30/2005	Data unusable
Wind River below Boysen Reservoir				
USGS	Wind River below Boysen Reservoir, WY	6259000	11/24/1953 to 12/16/2014	Lab and Field Data
EPA STORET	Wind River Canyon	G-53	1/9/1997 to 2/28/2006	Data unusable
EPA STORET	Wind River Canyon	205	1/9/1997 to 9/29/2010	Data unusable
EPA STORET	Wind River Canyon	1048	4/24/200 to 9/28/2011	Data unusable
EPA STORET	Wind River @ Wedding of the Waters last rest area	1049	4/27/2011 to 9/28/2011	Data unusable
Muskrat Creek near Shoshoni				
USGS	Muskrat Creek Near Shoshoni, WY	6239000	9/11/1950 to 9/12/1973	Temperature & Sediment Data only
Badwater Subbasin				
USGS	Red Creek near Arminto, WY	6256600	11/19/1949	Temperature & Sediment Data only
USGS	Badwater Creek at Lysite, WY	6256650	6/17/1966 to 7/12/2000	Lab and Field Data
USGS	Bridger Creek near Lysite, WY	6256800	3/31/1966 to 9/11/1973	Temperature & Sediment Data only
USGS	Dolus Creek near Lysite, WY	6256830	6/23/1966	Temperature & Sediment Data only
USGS	Dry Creek near Bonneville, WY	6256900	5/9/1967 to 9/1/1981	Lab and Field Data
USGS	Hoodoo Creek near Bonneville, WY	6256940	11/19/1949	Temperature & Sediment Data only
USGS	Badwater Creek at Bonneville, WY	6257000	11/19/1949 to 9/8/1973	Temperature & Sediment Data only
Lower Poison Creek Watershed				
USGS	Dead Man Gulch near Moneta, WY	6255200	11/19/1949	Temperature & Sediment Data only
USGS	Poison Creek near Shoshoni, WY	6255500	6/2/1949 to 7/13/2000	Lab and Field Data
Boysen Reservoir				
EPA STORET	Boysen Reservoir	1011	6/2/1999 to 9/28/2006	Lab and Field Data
EPA STORET	Boysen Reservoir	NLA06608-0950	8/2/2007	Data unusable
EPA STORET	WB163 - Wind River - Boysen	WB163	9/18/2001	Data unusable

Source: USGS 2015; EPA 2015
USGS = U.S. Geological Survey; EPA = U.S. Environmental Protection Agency

4.3.4.2 Wind River above Boysen Reservoir

USGS has collected water quality data at the Wind River above Boysen Reservoir (6236100) gaging station since January 1973. A statistical summary of the period of record (1973 to 2014) water quality data for select analytes[1] at this station is shown on Table 9.

The water is generally of calcium/sodium-sulfate type, with slightly elevated pH and low specific conductivities. According to the summary water quality statistics, the lab results for cyanide (2 samples) exceed the Wyoming DEQ Chronic Aquatic Life criteria. The field value for dissolved oxygen was slightly below the Wyoming DEQ criteria on several occasions. There were no other Wyoming DEQ surface water quality criteria exceedances. The water quality data are presented in Attachment C.

Table 9. Water Quality Data for Wind River above Boysen Reservoir, Wyoming (USGS 6236100)

Period of Record: January 4, 1873 to December 16, 2014							Wyoming DEQ Surface Water Criteria			
Analyte	Units	WQ Statistics					Aquatic Life		Human Health Consumption of	
		# of ND	Count	Min	Max	Avg.	Acute Value (µg/L)	Chronic Value (µg/L)	Fish and Drinking Water (µg/L)	Fish (µg/L)
Lab Data										
pH, Lab	SU	0	29	7.7	8.5	8.12		6.5-9.0		
E.C., Lab	µS/cm	0	29	218	1120	588.7				
Alkalinity (as CaCO3)	mg/L	0	2	127	149	138.0				
Hardness (as CaCO3)	mg/L	0	107	74	400	228.7				
SAR	None	0	107	0.5	2.7	1.27				
Nitrate as N, dissolved	µg/L	0	14	7	310	108.6			10000	
Nitrite as N, dissolved	µg/L	0	14	1	30	5.29			1000	
Nitrate/Nitrite as N, dissolved	µg/L	4	111	10	710	173.6			10000	
Nitrate/Nitrite as N, total	µg/L	0	56	100	600	193.0			10000	
Nitrogen, ammonia, dissolved	µg/L	0	5	10	340	76.00	4640	pH& temp dep.		
Nitrogen, ammonia, total	µ	0	56	10	260	78.39				
Ammonium, as NH4	mg/L	0	5	0.013	0.44	0.100				
Chloride	µg/L	0	109	900	3400 0	7206. 7	86000 0	230000		
Fluoride	µg/L	0	109	100	600	336			2000	
Sulfate	mg/L	0	109	29	400	156.5				

[1]Select analytes generally includes all aqueous matrix analytes that are major ions, physical properties, metals, or radiological analytes. Also included are all aqueous matrix analytes found on the WDEQ Surface Water Criteria – Priority and Non-Priority Pollutants lists (Tables 6 and Table 7, Wyoming DEQ 2013d).

Analyte	Units	Period of Record: January 4, 1873 to December 16, 2014					Wyoming DEQ Surface Water Criteria			
		WQ Statistics					Aquatic Life		Human Health Consumption of	
		# of ND	Count	Min	Max	Avg.	Acute Value (µg/L)	Chronic Value (µg/L)	Fish and Drinking Water (µg/L)	Fish (µg/L)
Calcium, dissolved	mg/L	0	107	20	96	58.1				
Calcium, total	mg/L	0	2	50.6	55.1	52.85				
Magnesium, dissolved	mg/L	0	107	5.5	39	20.37				
Magnesium, total	mg/L	0	2	16	17.3	16.65				
Potassium, dissolved	mg/L	0	107	0.8	5.2	2.79				
Potassium, total	mg/L	0	2	0.3	2.4	1.35				
Sodium, dissolved	mg/L	0	107	9.2	110	45.24				
Sodium, total	mg/L	0	2	34.6	62.6	48.60				
Cyanide	µg/L	0	2	10	10	10	22	5.2	140	140
Total Dissolved Solids, dried	mg/L	0	24	122	764	379.5				
Total Dissolved Solids	mg/L	0	107	115	775	397.1				
Total Suspended Solids	mg/L	0	52	9	3920	596.3				
TSS, temporal	tons/day	0	52	6.7	83300	9177				
Aluminum, dissolved	µg/L	0	2	2.2	3.1	2.7	750	87		
Arsenic, dissolved	µg/L	0	2	0.99	1.8	1.4	340	150	10	10
Arsenic, total	µg/L	0	2	2	2	2.00				
Barium, dissolved	µg/L	0	2	49.9	52.1	51.00			2000	
Barium, total	µg/L	0	2	48.2	62.4	55.30				
Beryllium, dissolved	µg/L	0	2	0.02	0.02	0.020			4	
Boron, dissolved	µg/L	0	28	30	120	73.43				
Cadmium, dissolved	µg/L	0	2	0.03	0.03	0.030	4.50	0.437	5	
Cadmium, total	µg/L	0	2	13	13	13.00				
Chromium, dissolved	µg/L	0	2	0.3	0.3	0.300	16	11	100	(total)
Chromium, total	µg/L	0	2	1	1	1.00	1122	145.9	100	(total)
Cobalt, dissolved	µg/L	0	2	0.093	0.203	0.148				
Copper, dissolved	µg/L	0	2	0.8	0.8	0.800	29.30	18.16	1000	
Copper, total	µg/L	0	2	20	20	20.00				
Iron, dissolved	µg/L	0	2	4	7.2	5.60		1000	300	
Iron, total	µg/L	0	2	412	716	564.0				
Lead, dissolved	µg/L	0	2	0.04	0.04	0.040	156.9	6.11	15	
Lead, total	µg/L	0	2	0.6	1.1	0.850				

Analyte	Units	Period of Record: January 4, 1873 to December 16, 2014 WQ Statistics # of ND	Count	Min	Max	Avg.	Wyoming DEQ Surface Water Criteria Aquatic Life Acute Value (µg/L)	Chronic Value (µg/L)	Human Health Consumption of Fish and Drinking Water (µg/L)	Fish (µg/L)
Lithium, dissolved	µg/L	0	2	12.5	12.7	12.60				
Manganese, dissolved	µg/L	0	2	1.6	8.23	4.92	5876	2292	50	
Manganese, total	µg/L	0	2	61.8	79.3	70.6				
Mercury, dissolved	µg/L	0	3	0.005	0.005	0.005	1.4	0.77	0.05	0.05
Mercury, total	µg/L	0	2	0.01	0.02	0.015				
Molybdenum, dissolved	µg/L	0	2	1.1	1.16	1.13				
Nickel, dissolved	µg/L	0	2	0.92	0.96	0.940	942.8	104.7	610	4600
Orthophosphate as P	mg/L	0	13	0.004	0.028	0.012				
Phosphorus, total as P	mg/L	0	123	0.004	0.65	0.103				
Phosphorus, total as PO4	mg/L	0	45	0.06	2	0.469				
Selenium, dissolved	µg/L	0	14	0.36	3	1.06	19.92	4.61	50	4200
Selenium, total	µg/L	0	3	1	3	2.33	20	5	50	4200
Silica, as SiO2	mg/L	0	108	6.26	23	11.23				
Silver, dissolved	µg/L	0	2	0.02	0.02	0.020	7.16		100	
Silver, total	µg/L	0	2	0.4	0.4	0.400				
Strontium, dissolved	µg/L	0	2	382	418	400.0				
Uranium, dissolved	µg/L	0	2	3.12	4.18	3.65				
Vanadium, dissolved	µg/L	0	2	2.6	3.1	2.85				
Zinc, dissolved	µg/L	0	2	2	2	2.00	236.2	238.1	5000	26000
Zinc, total	µg/L	0	2	31	31	31.00				
2,4-D, dissolved	µg/L	0	1	0.06	0.06	0.060				
2,4-D, total	µg/L	4	18	0.01	0.22	0.041			70	
4,4'-DDT, total	µg/L	8	8				0.55	0.001	0.00022	0.00022
Aldrin, total	µg/L	8	8				1.5		0.000049	0.00005
alpha-Endosulfan, dissolved	µg/L	0	1	0.006	0.006	0.006				
alpha-Endosulfan, total	µg/L	7	7				0.11	0.056	62	89
Atrazine, dissolved	µg/L	0	5	0.005	0.015	0.008			3	
Carbofuran, dissolved	µg/L	0	5	0.02	0.06	0.028			40	
Chlordane, total	µg/L	8	8				1.2	0.0043	0.0008	0.00081

		Period of Record: January 4, 1873 to December 16, 2014					Wyoming DEQ Surface Water Criteria			
Analyte	Units	WQ Statistics					Aquatic Life		Human Health Consumption of	
		# of ND	Count	Min	Max	Avg.	Acute Value (µg/L)	Chronic Value (µg/L)	Fish and Drinking Water (µg/L)	Fish (µg/L)
Chlorpyrifos, dissolved	µg/L	0	5	0.005	0.01	0.006	0.083	0.041		
Chlorpyrifos, total	µg/L	0	10	0.01	0.01	0.010				
Diazinon, dissolved	µg/L	0	5	0.005	0.006	0.005				
Diazinon, total	µg/L	8	20	0.01	0.01	0.010	0.17	0.17		
Dieldrin, dissolved	µg/L	0	5	0.005	0.008	0.006				
Dieldrin, total	µg/L	8	8				0.24	0.056	0.000052	0.000054
Dinoseb, dissolved	µg/L	0	1	0.06	0.06	0.060				
Endosulfan sulfate, dissolved	µg/L	0	1	0.016	0.016	0.016				
Endrin, total	µg/L	8	8				0.09	0.04	0.059	0.06
Glyphosate, dissolved	µg/L	0	1	0.02	0.02	0.020				
Heptachlor epoxide, total	µg/L	8	8				0.26	0.0038	0.000039	0.000039
Heptachlor, total	µg/L	8	8				0.26	0.0038	0.000079	0.000079
Malathion, dissolved	µg/L	0	5	0.009	0.027	0.019				
Malathion, total	µg/L	8	20	0.01	0.04	0.013		0.1		
Methoxychlor, total	µg/L	2	2					0.03	40	
Mirex, total	µg/L	4	4					0.001		
Oxamyl, dissolved	µg/L	0	1	0.12	0.12	0.120				
Parathion, dissolved	µg/L	0	4	0.007	0.01	0.008				
Parathion, total	µg/L	8	20	0.01	0.01	0.010				
PCBs, total	µg/L	8	8					0.014	0.000064	0.000064
Phenol, total	µg/L	0	1	33	33	33.00				
Picloram, dissolved	µg/L	0	1	0.1	0.1	0.100				
Picloram, total	µg/L	0	12	0.01	0.03	0.013				
Simazine, dissolved	µg/L	0	5	0.005	0.011	0.009			4	
Field Data										
Carbon dioxide, dissolved	mg/L	0	55	0.4	21	2.83				
Dissolved oxygen	mg/L	0	151	6.6	14.2	9.87		8		
Dissolved oxygen	%	0	64	76	149	103.8				
E.C., Field, 25C	µS/cm	0	100	193	1100	595.1				

Period of Record: January 4, 1873 to December 16, 2014								Wyoming DEQ Surface Water Criteria			
Analyte	Units	WQ Statistics						Aquatic Life		Human Health Consumption of	
		# of ND	Count	Min	Max	Avg.		Acute Value (µg/L)	Chronic Value (µg/L)	Fish and Drinking Water (µg/L)	Fish (µg/L)
pH, Field	SU	0	113	7.2	8.7	8.08			6.5-9.0		
Temperature, Field	Deg C	0	223	0	26	10.86					
Turbidity, Field	NTU	0	19	1.2	450	51.64					

Source: USGS 2015
ND – non detect
Shaded cells indicate values outside limits for similarly color-coded Wyoming DEQ water quality criteria.
Nitrogen, ammonia acute standard calculated based on the period of record average Field pH value (8.08 SU).
Aluminum chronic standard eliminated due to the period of record average pH and hardness values being above 7.0 and 50 mg/L, respectively.
Hardness dependent metals standards calculated based on the period of record average hardness value (228.7 mg/L).
Dissolved oxygen standard is taken from the most stringent 1-Day Minimum Cold Water Criteria (Attachment B).
The Wind River above the Boysen Reservoir is Class 2AB water. In Class 1, 2AB and 2A waters, radiological limit is 30 µg/L for uranium.
µg/L = micrograms per liter; SU = standard unit; µS/cm = micrograms Siemens per centimeter; mg/L = milligrams per liter; µ = micrograms; Deg C = degrees Celsius; NTU = nephelometric turbidity unit

4.3.4.3 Wind River below Boysen Reservoir

Downstream of the Boysen Reservoir Dam and upstream of Thermopolis, the Wind River is classified by Wyoming DEQ as Class 1 surface water, the highest class for surface water quality. The Wind River below the Boysen Reservoir Dam has the requirement that existing water quality must be preserved, regardless of the uses of the water (Wyoming DEQ 2013b).

USGS has collected water quality data at the Wind River below Boysen Reservoir (6259000) gaging station since November 1953, providing the largest surface water quality dataset in the analysis area. A statistical summary of the period of record (1953 to 2014) water quality data for select analytes at this station is presented in Table 10.

The water in the Wind River below Boysen Reservoir is generally of calcium-sulfate type, with slightly elevated pH and low specific conductivities. According to the summary water quality statistics, there have been occasional exceedances of Wyoming DEQ Human Health Consumption of Fish and Drinking Water criteria for fluoride, dissolved beryllium, dissolved lead, dissolved manganese, and gross beta particle emitters, and somewhat consistent exceedances of dissolved mercury. Wyoming DEQ Chronic Aquatic Life criteria for cyanide were exceeded in two samples. Wyoming DEQ Chronic Aquatic Life criteria were also regularly exceeded for dissolved cadmium and dissolved lead. Dissolved chromium and dissolved copper concentrations were occasionally outside the limits for Wyoming DEQ Acute Aquatic Life criteria. Field parameters for dissolved oxygen and pH were occasionally outside of their respective Wyoming DEQ Chronic Aquatic Life criteria ranges. The complete water quality data are presented in Attachment C.

Table 10. Water Quality Data for Wind River below Boysen Reservoir, Wyoming (USGS 6259000)

Period of Record: November 24, 1953 to December 16, 2004 12/16/2014						Wyoming DEQ Surface Water Criteria			
Analyte	Units	WQ Statistics				Aquatic Life		Human Health Consumption of	
		Count	Min	Max	Avg.	Acute Value (µg/L)	Chronic Value (µg/L)	Fish and Drinking Water (µg/L)	Fish (µg/L)
Lab Data									
pH, Lab	SU	193	7.9	8.9	8.34		6.5-9.0		
E.C., Lab	µS/cm	193	315	853	634.70				
Alkalinity (as CaCO3)	mg/L	94	91.6	182	153.72				
Hardness (as CaCO3)	mg/L	575	110	480	216.79				
SAR	None	574	0.95	3.7	1.91				
Nitrate as N, dissolved	µg/L	404	0	678	89.12			10000	
Nitrate as N, total	µg/L	67	0	610	160.57			10000	
Nitrite as N, dissolved	µg/L	112	1	20	3.54			1000	
Nitrate/Nitrite as N, dissolved	µg/L	190	0	2300	133.91			10000	
Nitrate/Nitrite as N, total	µg/L	51	0	1200	148.04			10000	
Nitrogen, ammonia, dissolved	µg/L	141	0	190	44.38	5620	pH + temp dep.		
Nitrogen, ammonia, total	µg/L	57	0	220	80.35				
Ammonia + org Nitrogen as N, dissolved	mg/L	16	0.22	1.4	0.62				
Ammonia + org Nitrogen as N, total	mg/L	103	0.2	2.1	0.56				
Chloride	µg/L	538	100	6600 0	8682.01	860000	230000		
Fluoride	µg/L	537	0	4000	398.31			2000	
Sulfate	mg/L	547	60.3	563	200.84				
Calcium, dissolved	mg/L	561	30	115	56.37				
Calcium, total	mg/L	2	56.6	63.4	60.00				
Magnesium, dissolved	mg/L	561	7.3	47	18.13				
Magnesium, total	mg/L	2	20.2	20.6	20.40				
Potassium, dissolved	mg/L	535	0.1	5	2.72				
Potassium, total	mg/L	2	0.1	2.8	1.45				
Sodium, dissolved	mg/L	574	23	156	65.19				
Sodium, total	mg/L	2	65.7	67.4	66.55				
Bacteria, Total Coliform	#/100ml	1	9	9	9.00				
Cyanide	µg/L	2	10	10	10.00	22	5.2	140	140
Dissolved Organic Carbon	mg/L	6	2.2	9.9	6.22				
Total Organic Carbon	mg/L	8	4.1	8.5	6.00				
Total Dissolved	mg/L	476	210	1420	460.06				

Period of Record: November 24, 1953 to December 16, 2004 12/16/2014						Wyoming DEQ Surface Water Criteria			
Analyte	Units	WQ Statistics				Aquatic Life		Human Health Consumption of	
		Count	Min	Max	Avg.	Acute Value (µg/L)	Chronic Value (µg/L)	Fish and Drinking Water (µg/L)	Fish (µg/L)
Solids, dried									
Total Dissolved Solids	mg/L	532	195	1050	441.54				
Total Suspended Solids	mg/L	55	1	63	13.60				
Total Suspended Solids	mg/L	4	1	3	1.50				
TSS, temporal	tons/day	54	0.99	479	63.27				
Aluminum, dissolved	µg/L	36	10	100	22.78	750			
Aluminum, total	µg/L	96	4.4	223	42.92	750			
Arsenic, dissolved	µg/L	153	0.77	4	1.99	340	150	10	10
Arsenic, total	µg/L	111	1.4	4	2.14				
Barium, dissolved	µg/L	56	50	200	67.46			2000	
Barium, total	µg/L	107	0	400	65.30				
Beryllium, dissolved	µg/L	39	0	10	1.24			4	
Beryllium, total	µg/L	98	0.01	10	0.44				
Boron, dissolved	µg/L	281	10	270	78.51				
Cadmium, dissolved	µg/L	53	1	2	1.04	4.27	0.42	5	
Cadmium, total	µg/L	9	0	13	3.33				
Chromium, dissolved	µg/L	54	0	20	3.22	16	11	100	(total)
Chromium, total	µg/L	13	0	20	4.77	1074.62	139.79		
Cobalt, dissolved	µg/L	49	1	3	2.92				
Cobalt, total	µg/L	6	0	1	0.33				
Copper, dissolved	µg/L	41	1	140	14.49	27.89	17.36	1000	
Copper, total	µg/L	7	20	270	127.14				
Iron, dissolved	µg/L	172	0	290	27.70		1000	300	
Iron, total	µg/L	96	10	190	45.42				
Lead, dissolved	µg/L	46	0	200	8.39	148.44	5.78	15	
Lead, total	µg/L	5	0	1	0.60				
Lithium, dissolved	µg/L	43	13	40	24.16				
Lithium, total	µg/L	4	10	30	20.00				
Manganese, dissolved	µg/L	140	0.51	240	16.85	5643.47	2227.06	50	
Manganese, total	µg/L	17	10	210	34.41				
Mercury, dissolved	µg/L	57	0	9	0.50	1.4	0.77	0.05	0.05
Mercury, total	µg/L	17	0	15	2.17				
Molybdenum, dissolved	µg/L	31	1	10	9.19				
Molybdenum, total	µg/L	4	2	2	2.00				
Nickel, dissolved	µg/L	23	0	20	6.57	901.80	100.16	610	4600
Nickel, total	µg/L	1	0	0	0.00				
Orthophosphate as P	mg/L	134	0.003	0.16	0.02				
Phosphorus, total as P	mg/L	163	0	0.27	0.03				
Selenium, dissolved	µg/L	59	0	2	1.07	19.92	4.61	50	4200
Selenium, total	µg/L	111	0	3	0.59	20	5	50	4200

Period of Record: November 24, 1953 to December 16, 2004 12/16/2014						Wyoming DEQ Surface Water Criteria			
Analyte	Units	WQ Statistics				Aquatic Life		Human Health Consumption of	
		Count	Min	Max	Avg.	Acute Value (µg/L)	Chronic Value (µg/L)	Fish and Drinking Water (µg/L)	Fish (µg/L)
Silica, as SiO2	mg/L	562	0.043	17	8.05				
Silver, dissolved	µg/L	56	0	4	0.93	6.54		100	
Silver, total	µg/L	17	0	1	0.22				
Strontium, dissolved	µg/L	39	350	740	583.08				
Uranium, dissolved	µg/L	13	5.2	11	8.72				
Vanadium, dissolved	µg/L	30	1	7	5.54				
Zinc, dissolved	µg/L	52	3	50	12.56	225.91	227.76	5000	26000
Zinc, total	µg/L	17	10	130	27.18				
Gross Alpha, dissolved	pCi/L	5	5.3	13	9.22	15	15	15	15
Gross Beta, dissolved	pCi/L	13	3.4	8	5.62	8 - 50	8 - 50	8 - 50	8 - 50
Radium 226, dissolved	µg/L	13	0.07	0.19	0.12	5	5	5	5
Field Data									
Carbon Dioxide, dissolved	mg/L	490	0.1	101	5.14				
Dissolved oxygen	mg/L	259	5	20.7	10.02		8.0		
Dissolved oxygen	%	153	68	187	105.46				
E.C., Field, 25C	µS/cm	562	320	1460	691.37				
pH, Field	SU	504	6.3	9.5	7.96		6.5-9.0		
Temperature, Field	Deg C	343	0	25	10.33				
Turbidity, Field	NTU	59	0.3	95	4.34				

Source: USGS 2015
Shaded cells indicate values outside limits for similarly color-coded Wyoming DEQ water quality criteria.
Nitrogen, ammonia acute standard calculated based on the period of record average field pH value (7.96 SU).
Aluminum chronic standard eliminated due to the period of record average pH and hardness values being above 7.0 and 50 mg/L, respectively.
Hardness dependent metals standards calculated based on the period of record average hardness value (217 mg/L).
Dissolved oxygen standard is taken from the most stringent 1-Day Minimum Cold Water Criteria (Attachment B).
The Wind River below the Boysen Dam is a Class 1 water. In Class 1, 2AB and 2A waters, radiological limits are 5 pCi/L for combined radium-226 and radium-228, 15 pCi/L for gross alpha particle activity (excluding radon and uranium), and 30 µg/L for uranium.
Gross beta MCL is 4 millirem/year annual dose equivalent to the total body or any internal organ. Calculated dose limit based on Sr-90 is 8 pCi/L,
EPA considers 50 pCi/L to be the level of concern for Gross Beta.
µg/L = micrograms per liter; SU = standard unit; µS/cm = micrograms Siemens per centimeter; mg/L = milligrams per liter; µ = micrograms; pCi/L = picocuries per liter; Deg C = degrees Celsius; NTU = nephelometric turbidity unit

In addition to the Wind River below Boysen Reservoir, Wyoming (USGS 6259000) gaging station water quality data, Encana collected surface water quality data at the outlet of the Boysen Reservoir between December 2010 and April 2013. A statistical summary of the Encana water quality data is shown on Table 11.

The water generally had slightly elevated pH and low specific conductivities. Upon inspection of the tabulated water quality data, the exceedances of pH and dissolved manganese appear to be suspect data. Both exceedances are isolated outliers that do not seem to fit with the rest of the dataset (Attachment C). There were no other Wyoming DEQ surface water quality criteria exceedances.

Table 11. Encana Water Quality Data Collected at the Outlet from Boysen Reservoir

Period of Record: December 2010 to April 2013							Wyoming DEQ Surface Water Criteria			
Analyte	Units	WQ Statistics					Aquatic Life		Human Health Consumption of	
		# of ND	Count	Min	Max	Avg.	Acute Value (µg/L)	Chronic Value (µg/L)	Fish and Drinking Water (µg/L)	Fish (µg/L)
Lab Data										
pH, Lab	SU	0	25	7.97	9.54	8.51		6.5-9.0		
E.C., Lab	µS/cm	0	25	240	764	537.7				
Hardness (as CaCO3)	mg/L	0	24	87	310	180.1				
Chloride	mg/L	0	25	4200	16000	10427	860000	230000		
Fluoride	mg/L	13	25	200	500	341.7			2000	
Sulfate	mg/L	0	25	84	240	139.0				
Total Dissolved Solids	mg/L	0	25	230	490	345.8				
Aluminum, dissolved	µg/L	15	25	4.3	45	16.76	750	87		
Arsenic, dissolved	µg/L	8	25	1.5	2.4	1.91	340	150	10	10
Beryllium, dissolved	µg/L	25	25						4	
Cadmium, dissolved	µg/L	25	25				3.6	0.4	5	
Chromium, dissolved	µg/L	20	25	0.5	3	1.09	16	11	100	(total)
Copper, dissolved	µg/L	12	25	0.54	1.9	0.96	23.4	14.8	1000	
Lead, dissolved	µg/L	23	25	0.14	0.15	0.15	121.7	4.7	15	
Manganese, dissolved	µg/L	8	25	0.53	182	15.05	4887.5	2011.9	50	
Mercury, dissolved	µg/L	25	25				1.4	0.77	0.05	0.051
Nickel, dissolved	µg/L	11	25	0.56	12.9	1.89	769.9	85.5	610	4600
Selenium, total	µg/L	24	24				20	5	50	4200
Silver, dissolved	µg/L	25	25				4.7		100	
Thallium, dissolved	µg/L	24	25	0.52	0.52	0.52				
Zinc, dissolved	µg/L	23	25	5.2	10.4	7.80	192.8	194.4	5000	26000

Source Encana 2013
Shaded cells indicate values outside limits for similarly color-coded Wyoming DEQ water quality criteria.
Aluminum chronic standard eliminated due to the period of record average pH and hardness values being above 7.0 and 50 mg/L respectively.
Hardness dependent metals standards calculated based on the period of record average hardness value (180 mg/L).
Note that the exceedances of pH and dissolved manganese are considered suspect data.
µg/L = micrograms per liter; SU = standard unit; µS/cm = micrograms Siemens per centimeter; mg/L = milligrams per liter

4.3.4.4 Muskrat Creek

USGS collected suspended sediment and water temperature data at the Muskrat Creek near Shoshoni, Wyoming (USGS 6239000) gaging station between September 1950 and September 1973. There are no Wyoming DEQ water quality criteria for these parameters, but Muskrat Creek carries a substantial load of sediment from a qualitative standpoint (Table 12).

Table 12. Water Quality Data for Muskrat Creek near Shoshoni, Wyoming (USGS 6239000)

	Period of Record: September 11, 1950 to September 12, 1973				
Analyte	Units	WQ Statistics			
		Count	Min	Max	Avg.
Lab Data					
Total Suspended Solids	mg/L	33	3210	108000	31197.6
TSS, temporal	tons/day	33	38	130000	16069.4
Field Data					
Temperature, Field	Deg C	31	1	25.6	13.21

Source: USGS 2015
mg/L = milligrams per liter; Deg C = degrees Celsius

4.3.4.5 Badwater Creek Subbasin

USGS collected suspended sediment and water temperature data at seven USGS gaging stations in the Badwater Creek subbasin between November 1949 and July 2000 (Table 8):

- Badwater Creek at Bonneville, Wyoming (USGS 6257000)
- Hoodoo Creek near Bonneville, Wyoming (USGS 6256940)
- Dry Creek near Bonneville, Wyoming (USGS 6256900)
- Dolus Creek near Lysite, Wyoming (USGS 6256830)
- Bridger Creek near Lysite, Wyoming (USGS 6256800)
- Badwater Creek at Lysite, Wyoming (USGS 6256650)
- Red Creek near Arminto, Wyoming (USGS 6256600)

There are no Wyoming DEQ water quality criteria for these parameters, but Badwater Creek and its tributaries generally carry a substantial load of sediment from a qualitative standpoint (Table 13).

Table 13. Water Quality for the Badwater Subbasin (Seven USGS Gaging Stations)

	Period of Record: November 19, 1949 to July 12, 2000				
Analyte	Units	WQ Statistics			
		Count	Min	Max	Avg.
Lab Data					
Total Suspended Solids	mg/L	278	16	204000	17882.6
TSS, temporal	tons/day	276	0.02	1520000	27141.5
Field Data					
Temperature, Field	Degrees Celsius	247	0	29.5	11.38

Source: USGS 2015
Includes data from USGS Stations: 6257000, 6256940, 6256900, 6256830, 6256800, 6256650, and 6256600.
mg/L = milligrams per liter; Deg C = degrees Celsius

4.3.4.6 Lower Poison Creek Watershed

USGS collected suspended sediment and water temperature data at two USGS gaging stations: Poison Creek near Shoshoni, Wyoming (USGS 6255500) and Dead Man Gulch near Moneta, Wyoming (USGS 6255200) (USGS 2015) (Table 8), in the Lower Poison Creek watershed (Figure 6). Data were collected between November 1949 and July 2000. There are no Wyoming DEQ water quality criteria for these parameters, but Poison Creek and its tributary often carry a substantial load of sediment from a qualitative standpoint (Table 14).

Table 14. Water Quality Data for the Lower Poison Creek Watershed (Two USGS Gaging Stations)

Period of Record: November 19, 1949 to July 12, 2000					
Analyte	Units	WQ Statistics			
		Count	Min	Max	Avg.
Lab Data					
Total Suspended Solids	mg/L	15	54	101000	29194.27
TSS, temporal	tons/day	11	0.03	67100	8686.51
Field Data					
Temperature, Field	Degrees Celsius	3	15.6	25	21.37

Source: USGS 2015
Includes data from USGS Stations: 6255500 and 6255200.
mg/L = milligrams per liter; Deg C = degrees Celsius

4.3.4.7 Boysen Reservoir

Wyoming DEQ classifies water in the Boysen Reservoir as Class 2AB surface water (Wyoming DEQ 2013b). Boysen Reservoir is actively used for recreation, fishing, and as a water supply. Water quality data for Boysen Reservoir were obtained via the EPA STORET database from three stations:

- Boysen Reservoir (Station 1011)
- Boysen Reservoir (Station NLA06608-0950)
- WB163 - Wind River – Boysen (Station WB163)

The Wind River Environmental Quality Commission, the Wyoming DEQ Watershed Program, and the EPA National Aquatic Resources Survey collected data between June 1999 and August 2007. Unfortunately, much of the water quality data in these datasets has been determined to be unusable, due to apparent errors in reporting units and generally suspect data. Due to additional uncertainty in station coordinate location, the water quality data (only one sample each) for stations NLA06608-0950 and WB163 are considered unusable and were not included in the analysis presented in this report. A statistical summary of the period of record water quality data for select analytes at Boysen Reservoir (Station 1011) is shown on Table 15.

According to the summary water quality statistics, there have been occasional exceedances of Wyoming DEQ Chronic Aquatic Life criteria for field pH. The water quality data are presented in Attachment C.

Table 15. Water Quality Data for Boysen Reservoir (EPA STORET Station 1011)

		Period of Record: July 2, 1999 to August 2, 2007					Wyoming DEQ Surface Water Criteria			
		WQ Statistics					Aquatic Life		Human Health Consumption of	
Analyte	Units	# of ND	Count	Min	Max	Avg.	Acute Value (µg/L)	Chronic Value (µg/L)	Fish and Drinking Water (µg/L)	Fish (µg/L)
Lab Data										
pH, Lab	SU	0	16	7.92	8.97	8.4		6.5-9.0		
Chloride	µg/L	0	16	1800	8200	4756.3	860000	230000		
Fluoride	µg/L	2	16	100	350	248.6			2000	
Potassium, dissolved	µg/L	0	16	1100	3900	2268.8				
Total Dissolved Solids	mg/L	0	17	100	1000	613.2				
Total Suspended Solids	µg/L	0	15	2000	9000	6133.3				
Field Data										
Dissolved oxygen	µg/L	0	42	20	9970	4139.5		8		
E.C., Field, 25C	µS/cm	0	9	100	800	466.7				
pH, Field	SU	0	44	7.3	9.02	8.1		6.5-9.0		
Turbidity, Field	NTU	0	43	0.2	9.9	5.1				

Source: EPA 2015
Shaded cells indicate values outside limits for similarly color-coded Wyoming DEQ water quality criteria.
ND – non-detect
STORET data for station NLA06608-0950 (Boysen Reservoir) and station WB163 (WB163 Wind River – Boysen) are considered unusable and are not included in this summary table.
µg/L = micrograms per liter; SU = standard unit; µS/cm = micrograms Siemens per centimeter; mg/L = milligrams per liter; NTU = nephelometric turbidity unit

4.3.4.8 Springs

USGS collected springwater samples at 20 locations in the analysis area in August 1991 (Table 16). These locations have been divided into five groups based on physical location:

- Upper Poison Creek watershed (one station)
- Alkali Creek watershed (one station)
- Bridger Creek watershed (12 stations)
- Upper Muskrat Creek watershed (two stations)
- Conant Creek watershed (four stations)

The locations of the spring sampling locations are shown on Figures 5 and 6. The spring water quality data are presented in Attachment C.

Table 16. Spring Sampling Sites

Station Type	Spring Name	Station ID	Period of Record	Comments
Upper Poison Creek Watershed				
USGS	37-089-31ccc01	430738107342301	8/18/1991	Lab and Field Data
Alkali Creek Watershed				
USGS	37-089-18ada01	431050107332301	8/18/1991	Lab and Field Data
Bridger Creek Watershed				
USGS	40-091-19ddb01	432456107474801	8/18/1991	Lab and Field Data
USGS	40-090-12abc01	432720107345701	8/18/1991	Lab and Field Data
USGS	40-089-06bca01	432803107341701	8/18/1991	Lab and Field Data
USGS	41-092-33daa01	432838107534501	8/18/1991	Lab and Field Data
USGS	41-091-32aac01	432859107475101	8/18/1991	Lab and Field Data
USGS	41-091-27dcc01	432912107450001	8/18/1991	Lab and Field Data
USGS	41-090-29dbc01	432925107405901	8/18/1991	Lab and Field Data
USGS	41-092-27dac01	432925107524901	8/18/1991	Lab and Field Data
USGS	41-091-27dbc01	432929107454801	8/18/1991	Lab and Field Data
USGS	41-091-23ddd01	433006107441401	8/18/1991	Lab and Field Data
USGS	41-091-13cdc01	433057107434801	8/18/1991	Lab and Field Data
USGS	41-090-04baa01	433335107395801	8/18/1991	Lab and Field Data
Upper Muskrat Creek Watershed				
USGS	32-090-11aaa01	424602107335001	8/18/1991	Lab and Field Data
USGS	33-090-28abb01	424834107374001	8/18/1991	Lab and Field Data
Conant Creek Watershed				
USGS	Lat-Long 42.4344°N-107.5953°W	424344107595301	8/18/1991	Lab and Field Data
USGS	33-094-26ddb01	424802108030701	8/18/1991	Lab and Field Data
USGS	33-094-27adb01	424826108043401	8/18/1991	Lab and Field Data
USGS	33-094-23dbd01	424859108031901	8/18/1991	Lab and Field Data

Source: USGS 2015
USGS = U.S. Geological Survey

4.3.4.9 Upper Poison Creek Watershed

USGS collected a single water quality sample at USGS Spring 37-089-31ccc01 (USGS 430738107342301) on August 18, 1991 (Table 16). The field and analytical lab water quality data are shown on Table 17. The water is generally of sodium-sulfate type, with slightly elevated pH and moderate specific conductivity. There are no Wyoming DEQ surface water quality criteria exceedances.

Table 17. Water Quality Data for Spring 37-089-31ccc01 (USGS 430738107342301)

Analyte	Units	Sample Date	Wyoming DEQ Surface Water Criteria			
			Aquatic Life		Human Health Consumption of	
		8/18/1991	Acute Value (µg/L)	Chronic Value (µg/L)	Fish and Drinking Water (µg/L)	Fish (µg/L)
Lab Data						
pH, Lab	SU	7.9		6.5-9.0		
E.C., Lab	µS/cm	1220				
Hardness (as CaCO3)	mg/L	92.1				
SAR	None	10.5				
Nitrate as N, dissolved	µg/L	< 50			10000	
Nitrate/Nitrite as N, dissolved	µg/L	< 50			10000	
Nitrite as N, dissolved	µg/L	< 50			1000	
Nitrogen, ammonia	µg/L	980	2140	1090		
Chloride	µg/L	8100	860000	230000		
Fluoride	µg/L	500			2000	
Sulfate	mg/L	440				
Calcium, dissolved	mg/L	22				
Magnesium, dissolved	mg/L	8.6				
Potassium, dissolved	mg/L	4.5				
Sodium, dissolved	mg/L	230				
Total Dissolved Solids	mg/L	833				
Aluminum, dissolved	µg/L	<10	750			
Arsenic, dissolved	µg/L	<1	340	150	10	10
Barium, dissolved	µg/L	8			2000	
Beryllium, dissolved	µg/L	<0.50			4	
Boron, dissolved	µg/L	140				
Cadmium, dissolved	µg/L	<1.0	1.9	0.2	5	
Chromium, dissolved	µg/L	<1	16	11	100	(total)
Cobalt, dissolved	µg/L	<3.0				
Copper, dissolved	µg/L	<1.0	12.4	8.3	1000	
Iron, dissolved	µg/L	10		1000	300	
Lead, dissolved	µg/L	<1	59	2	15	
Lithium, dissolved	µg/L	63				
Manganese, dissolved	µg/L	8	2916	1397	50	
Mercury, dissolved	µg/L	<0.1	1.4	0.77	0.05	0.051
Orthophosphate as P	mg/L	<0.01				
Phosphorus, total as P	mg/L	0.02				
Selenium, dissolved	µg/L	< 1	19.92	4.61	50	4200
Silica, as SiO2	mg/L	11				
Silver, dissolved	µg/L	<1.0	1.5		100	
Strontium, dissolved	µg/L	1500				

		Sample Date	Wyoming DEQ Surface Water Criteria			
			Aquatic Life		Human Health Consumption of	
Analyte	Units	8/18/1991	Acute Value (µg/L)	Chronic Value (µg/L)	Fish and Drinking Water (µg/L)	Fish (µg/L)
Zinc, dissolved	µg/L	<3.0	109	110	5000	26000
Field Data						
Carbon Dioxide, dissolved	mg/L	1				
E.C., Field, 25C	µS/cm	1240				
pH, Field*	SU	8.5		6.5-9.0		
Temperature, Field	Deg C	11.5				

Source: USGS 2015
Nitrogen, ammonia acute standard calculated based on the Field pH value (7.96 SU).
Nitrogen, ammonia chronic standard calculated based on field pH value (8.5 SU) and field temp value (11.5 Deg C).
Aluminum chronic standard eliminated due to the pH and hardness values being above 7.0 and 50 mg/L, respectively.
Hardness dependent metals standards calculated based on the hardness value (92 mg/L).
Numbers with "<" indicate value was below detection limit.

4.3.4.10 Alkali Creek Watershed

USGS collected a single water quality sample at Spring 37-089-18ada01 (USGS 431050107332301) on August 18, 1991 (Table 16). The field and analytical lab water quality data are shown on Table 18. The water is generally of sodium-sulfate type, with elevated pH and moderate specific conductivity. The Wyoming DEQ Chronic Aquatic Life criterion for field pH was exceeded in this sample.

Table 18. Water Quality Data for Spring 37-089-18ada01 (USGS 431050107332301)

		Date Collected	Wyoming DEQ Surface Water Criteria			
			Aquatic Life		Human Health Consumption of	
Analyte	Units	8/18/1991	Acute Value (µg/L)	Chronic Value (µg/L)	Fish and Drinking Water (µg/L)	Fish (µg/L)
Lab Data						
pH, Lab	SU	8.7		6.5-9.0		
E.C., Lab	µS/cm	1460				
Hardness (as CaCO3)	mg/L	7.85				
SAR	None	49.7				
Nitrate as N, dissolved	µg/L	<30			10000	
Nitrate/Nitrite as N, dissolved	µg/L	<50			10000	
Nitrite as N, dissolved	µg/L	20			1000	
Nitrogen, ammonia	µg/L	70	885	486		
Chloride	µg/L	7000	860000.0	230000		
Fluoride	µg/L	1300			2000	
Sulfate	mg/L	450				
Calcium, dissolved	mg/L	2.6				
Magnesium, dissolved	mg/L	0.33				
Potassium, dissolved	mg/L	1				
Sodium, dissolved	mg/L	320				
Carbon Dioxide, dissolved	mg/L	0.4				
Total Dissolved Solids	mg/L	940				
Iron, dissolved	µg/L	19		1000	300	

Analyte	Units	Date Collected 8/18/1991	Wyoming DEQ Surface Water Criteria: Aquatic Life: Acute Value (µg/L)	Aquatic Life: Chronic Value (µg/L)	Human Health Consumption of: Fish and Drinking Water (µg/L)	Human Health Consumption of: Fish (µg/L)
Manganese, dissolved	µg/L	2	439	367	50	
Orthophosphate as P	mg/L	0.03				
Phosphorus, total as P	mg/L	0.03				
Selenium, dissolved	µg/L	<1	19.92	4.61	50	4200
Silica, as SiO2	mg/L	7.2				
Field Data						
E.C., Field, 25C	µS/cm	1560				
pH, Field	SU	9.1		6.5-9.0		
Temperature, Field	Deg C	11.5				

Source: USGS 2015
Shaded cells indicate values outside limits for similarly color-coded Wyoming DEQ water quality criteria.
Nitrogen, ammonia acute standard calculated based on the field pH value (9.1 SU).
Nitrogen, ammonia chronic standard calculated based on the field pH value (9.1 SU) and the field temp. value (11.5 Deg C).
Hardness dependent metals standards calculated based on the hardness value (7.85 mg/L).
Numbers with "<" indicate value was below laboratory detection limit.
µg/L = micrograms per liter; SU = standard unit; µS/cm = micrograms Siemens per centimeter; mg/L = milligrams per liter; Deg C = degrees Celsius

4.3.4.11 Bridger Creek Watershed

USGS collected water quality samples at 12 USGS stations in the Bridger Creek watershed on August 18, 1991 (Table 16). Summary statistics of these field and analytical laboratory water quality data are presented in Table 19. Based on the summary statistics, the water is generally of calcium-sulfate type and has slightly elevated pH and low specific conductivity. There are no Wyoming DEQ surface water quality criteria exceedances.

Table 19. Springwater Quality Data in Bridger Creek Watershed (12 USGS Stations)

Analyte	Units	All Samples Collected on 8/18/91 – WQ Statistics: # of ND	Count	Min	Max	Avg.	Wyoming DEQ Surface Water Criteria – Aquatic Life: Acute Value (µg/L)	Chronic Value (µg/L)	Human Health Consumption of: Fish and Drinking Water (µg/L)	Fish (µg/L)
Lab Data										
pH, Lab	SU	0	12	7.3	8.3	8.03		6.5-9.0		
E.C., Lab	µS/cm	0	12	138	798	463.58				
Hardness (as CaCO3)	mg/L	0	12	59.8	366	218.20				
SAR	None	0	12	0.05	3.24	0.45				
Nitrate as N, dissolved	µg/L	0	3	640	1300	1013.33			10000	
Nitrate/Nitrite as N, dissolved	µg/L	1	12	190	1300	648.18			10000	
Nitrite as N, dissolved	µg/L	3	3	0	0				1000	
Nitrogen, ammonia	µg/L	0	3	20	20	20.00	9650	pH& temp dep.		
Chloride	µg/L	0	12	800	6000	2291.67	860000	230000		
Fluoride	µg/L	0	12	0.1	0.8	0.31			2000	
Sulfate	mg/L	0	12	8.3	200	65.03				

Analyte	Units	All Samples Collected on 8/18/91					Wyoming DEQ Surface Water Criteria			
		WQ Statistics					Aquatic Life		Human Health Consumption of	
		# of ND	Count	Min	Max	Avg.	Acute Value (µg/L)	Chronic Value (µg/L)	Fish and Drinking Water (µg/L)	Fish (µg/L)
Calcium, dissolved	mg/L	0	12	18	89	51.17				
Magnesium, dissolved	mg/L	0	12	3.6	35	21.98				
Potassium, dissolved	mg/L	0	12	0.8	4.6	2.19				
Sodium, dissolved	mg/L	0	12	1.8	87	13.90				
Total Dissolved Solids	mg/L	0	12	85	514	277.33				
Aluminum, dissolved	µg/L	0	1	10	10	10.00	750			
Arsenic, dissolved	µg/L	1	1	0	0		340	150	10	10
Barium, dissolved	µg/L	0	1	28	28	28.00			2000	
Beryllium, dissolved	µg/L	1	1	0	0				4	
Boron, dissolved	µg/L	1	10	10	380	66.67				
Cadmium, dissolved	µg/L	1	1	0	0		4.3	0.4	5	
Chromium, dissolved	µg/L	1	1	0	0		16	11	100	(total)
Cobalt, dissolved	µg/L	1	1	0	0					
Copper, dissolved	µg/L	1	1	0	0		28.0	17.4	1000	
Iron, dissolved	µg/L	1	10	7	15	10.67		1000.0	300	
Lead, dissolved	µg/L	1	1	0	0		149.2	5.8	15	
Lithium, dissolved	µg/L	0	1	7	7	7.00				
Manganese, dissolved	µg/L	7	10	5	12	9.33	5663.5	2232.6	50	
Mercury, dissolved	µg/L	1	1	0	0		1.4	0.8	0.05	0.051
Orthophosphate as P	mg/L	2	3	0.02	0.02	0.02				
Phosphorus, total as P	mg/L	4	11	0.01	0.06	0.03				
Selenium, dissolved	µg/L	3	8	2	8	4.00	19.9	4.6	50	4200
Silica, as SiO2	mg/L	0	12	7.2	18	13.57				
Silver, dissolved	µg/L	0	1	3	3	3.00	6.6		100	
Strontium, dissolved	µg/L	0	1	130	130	130.00				
Zinc, dissolved	µg/L	0	1	5	5	5.00	226.8	228.6	5000	26000
Uranium, dissolved	µg/L	0	1	1.1	1.1	1.10	30	30	30	30
Radium 226, total	pCi/L	0	1	0.22	0.22	0.22	5.0	5.0	5	5
Field Data										
Carbon dioxide, dissolved	mg/L	0	12	2.1	18	7.97				
E.C., Field, 25C	µS/cm	0	12	155	880	495.83				
pH, Field	SU	0	12	7	8.2	7.68		6.5-9.0		
Temperature, Field	Deg C	0	12	6	12	8.79				

Source: USGS 2015

Summary table includes data from 12 USGS Stations: 432456107474801, 432720107345701, 432803107341701, 432838107534501, 432859107475101, 432912107450001, 432925107405901, 432925107524901, 432929107454801, 433006107441401, 433057107434801, and 433335107395801

ND – non-detect

Nitrogen, ammonia acute standard calculated based on the average field pH value (7.68 SU).

Aluminum chronic standard eliminated due to the average pH and hardness values being above 7.0 and 50 mg/L, respectively.

Hardness dependent metals standards calculated based on the average hardness value (218 mg/L).

Bridger Creek is a Class 2AB water. In Class 1, 2AB and 2A waters, radiological limits are 5 pCi/L for combined radium-226 and radium-228, and 30 µg/L for uranium.

There are no exceedances in this dataset.

µg/L = micrograms per liter; SU = standard unit; □S/cm = micrograms Siemens per centimeter; mg/L = milligrams per liter; pCi/L = picocuries per liter; Deg C = degrees Celsius

4.3.4.12 Upper Muskrat Creek Watershed

USGS collected water quality samples at two USGS stations in the Upper Muskrat Creek watershed, Spring 33-090-28abb01 (USGS 424834107374001) and Spring 32-090-11aaa01 (USGS 424602107335001) (Table 16), on August 18, 1991. The summary statistics of the field and analytical laboratory data are shown on Table 20. Based on the summary statistics, the water is generally of calcium-sulfate type, with near neutral pH and somewhat elevated specific conductivity. The Wyoming DEQ Human Health Consumption of Fish and Drinking Water criterion for dissolved manganese was exceeded in one sample.

Table 20. Springwater Quality Data in the Upper Muskrat Creek Watershed

Analyte	Units	All Samples Collected on 8/18/91					Wyoming DEQ Surface Water Criteria			
		WQ Statistics					Aquatic Life		Human Health Consumption of	
		# of ND	Count	Min	Max	Avg.	Acute Value (µg/L)	Chronic Value (µg/L)	Fish and Drinking Water (µg/L)	Fish (µg/L)
Lab Data										
pH, Lab	SU	0	1	7.7	7.7	7.70		6.5-9.0		
E.C., Lab	µS/cm	0	1	1630	1630	1630				
Hardness (as CaCO3)	mg/L	0	2	19.9	689	354.45				
SAR	None	0	2	1.82	7.71	4.77				
Nitrate as N, dissolved	µg/L	1	1	0	0	0.00			10000	
Nitrate/Nitrite as N, diss	µg/L	1	2	1500	1500	1500.00			10000	
Nitrite as N, dissolved	µg/L	1	1	0	0	0.00			1000	
Nitrogen, ammonia	µg/L	0	1	10	10	10.00	4640	pH + temp dep.		
Chloride	µg/L	0	2	2400	14000	8200.00	860000	230000		
Fluoride	µg/L	0	2	300	500	400.00			2000	
Sulfate	mg/L	0	2	23	760	391.50				
Calcium, dissolved	mg/L	0	2	7.8	220	113.90				
Magnesium, dissolved	mg/L	0	2	0.1	34	17.05				
Potassium, dissolved	mg/L	0	2	7.2	16	11.60				
Sodium, dissolved	mg/L	0	2	79	110	94.50				
Total Diss. Solids, dried	mg/L	0	1	271	271	271.00				
Total Dissolved Solids	mg/L	0	2	281	1300	790.50				
Boron, dissolved	µg/L	0	1	160	160	160.00				
Iron, dissolved	µg/L	0	1	14	14	14.00		1000	300	
Iron, total	µg/L	0	1	40	40	40.00				
Manganese, dissolved	µg/L	0	1	54	54	54.00	8223	2906	50	
Orthophosphate as P	mg/L	1	1	0	0					
Phosphorus, total as P	mg/L	0	1	0.01	0.01	0.01				
Selenium,	µg/L	1	1	0	0		19.92	4.61	50	4200

dissolved										
Silica, as SiO2	mg/L	0	2	29	53	41.00				
Uranium, dissolved	µg/L	0	1	76	76	76.00				
Radium 226, total	pCi/L	0	1	0.4	0.4	0.40	60	60	60	60
Field Data										
Carbon Dioxide, diss.	mg/L	0	2	2.5	4.2	3.35				
E.C., Field, 25C	µS/cm	0	2	362	1660	1011.00				
pH, Field	SU	0	2	7.9	8.2	8.05		6.5-9.0		
Temperature, Field	Deg C	0	2	8.9	12.5	10.70				

Source: USGS 2015
Summary table includes data from two USGS Stations, 424602107335001 and 424834107374001
Shaded cells indicate values outside limits for similarly color-coded Wyoming DEQ water quality criteria.
ND – non-detect
Nitrogen, ammonia acute standard calculated based on the average field pH value (8.05 SU).
Hardness dependent metals standards calculated based on the average hardness value (354 mg/L).
Muskrat Creek is a Class 2C water. In Class 2B, 2C, 2D, 3 and 4 waters, the total radium-226 concentration must not exceed 60 pCi/L.
µg/L = micrograms per liter; SU = standard unit; µS/cm = micrograms Siemens per centimeter; mg/L = milligrams per liter; pCi/L = picocuries per liter; Deg C = degrees Celsius

4.3.4.13 Conant Creek Watershed

USGS collected water quality samples at four USGS spring stations in the Conant Creek watershed, Lat-Long 4243441075953 (USGS 424344107595301), Spring 33-094-26ddb01 (USGS 424802108030701), Station 33-094-27adb01 (USGS 424826108043401), and Spring 33-094-23dbd01 (USGS 424859108031901) (Table 16), on August 18, 1991. The summary statistics of the water quality data are shown on Table 21. Based on the summary statistics, the water is generally of sodium-sulfate type, with near neutral pH and somewhat elevated specific conductivity. The Wyoming DEQ Human Health Consumption of Fish and Drinking Water criterion for fluoride was equal to the limit in the sample taken from Spring 33-094-23dbd01.

Table 21. Springwater Quality Data in the Conant Creek Watershed (Four USGS Stations)

Analyte	Units	All Samples Collected on 8/18/91					Wyoming DEQ Surface Water Criteria			
		WQ Statistics					Aquatic Life		Human Health Consumption of	
		# of ND	Count	Min	Max	Avg.	Acute Value (µg/L)	Chronic Value (µg/L)	Fish and Drinking Water	Fish (µg/L)
Lab Data										
pH, Lab	SU	0	4	7.5	7.9	7.73		6.5-9.0		
E.C., Lab	µS/cm	0	4	549	2050	1246.25				
Hardness (as CaCO3)	mg/L	0	4	54.4	585	276.35				
SAR	None	0	4	0.6	12.6	6.31				
Nitrate as N, dissolved	µg/L	2	4	190	250	220.00			10000	
Nitrate/Nitrite as N, diss.	µg/L	2	4	190	250	220.00			10000	
Nitrite as N, dissolved	µg/L	4	4	0	0	0.00			1000	
Nitrogen, ammonia	µg/L	1	4	30	60	40.00	15400	pH + temp dep.		
Chloride	µg/L	0	4	5700	59000	28700.00	86000 0	230000		

Analyte	Units	All Samples Collected on 8/18/91					Wyoming DEQ Surface Water Criteria			
		WQ Statistics					Aquatic Life		Human Health Consumption of	
		# of ND	Count	Min	Max	Avg.	Acute Value (µg/L)	Chronic Value (µg/L)	Fish and Drinking Water	Fish (µg/L)
Fluoride	µg/L	0	4	700	2000	1450.00			2000	
Sulfate	mg/L	0	4	110	760	442.50				
Calcium, dissolved	mg/L	0	4	17	150	76.00				
Magnesium, dissolved	mg/L	0	4	2.9	51	20.98				
Potassium, dissolved	mg/L	0	4	1.9	17	8.45				
Sodium, dissolved	mg/L	0	4	23	400	170.50				
Total Dissolved Solids	mg/L	0	4	397	1470	888.75				
Iron, dissolved	µg/L	0	1	53	53	53.00		1000	300	
Manganese, dissolved	µg/L	0	1	20	20	20.00	6790	2538	50	
Orthophosphate as P	mg/L	3	4	0.26	0.26	0.26				
Phosphorus, total as P	mg/L	2	4	0.05	0.25	0.15				
Selenium, dissolved	µg/L	1	2	5	5	5.00	19.92	4.61	50	4200
Silica, as SiO2	mg/L	0	4	13	24	17.75				
Field Data										
Carbon Dioxide, diss.	mg/L	0	4	5	36	18.75				
E.C., Field, 25C	µS/cm	0	4	690	2070	1302.50				
pH, Field	SU	0	4	7.2	7.7	7.40		6.5-9.0		
Temperature, Field	Deg C	0	4	7	16	11.00				

Source: USGS 2015
Summary table includes data from four USGS Stations: 424344107595301, 424802108030701, 424826108043401, and 424859108031901
Shaded cells indicate values outside limits for similarly color-coded Wyoming DEQ water quality criteria.
ND – non-detect
Nitrogen, ammonia acute standard calculated based on the average Field pH value (7.4 SU).
Hardness dependent metals standards calculated based on the average hardness value (276 mg/L).
µg/L = micrograms per liter; SU = standard unit; µS/cm = micrograms Siemens per centimeter; mg/L = milligrams per literDeg C = degrees Celsius

5.0 GROUNDWATER HYDROLOGY

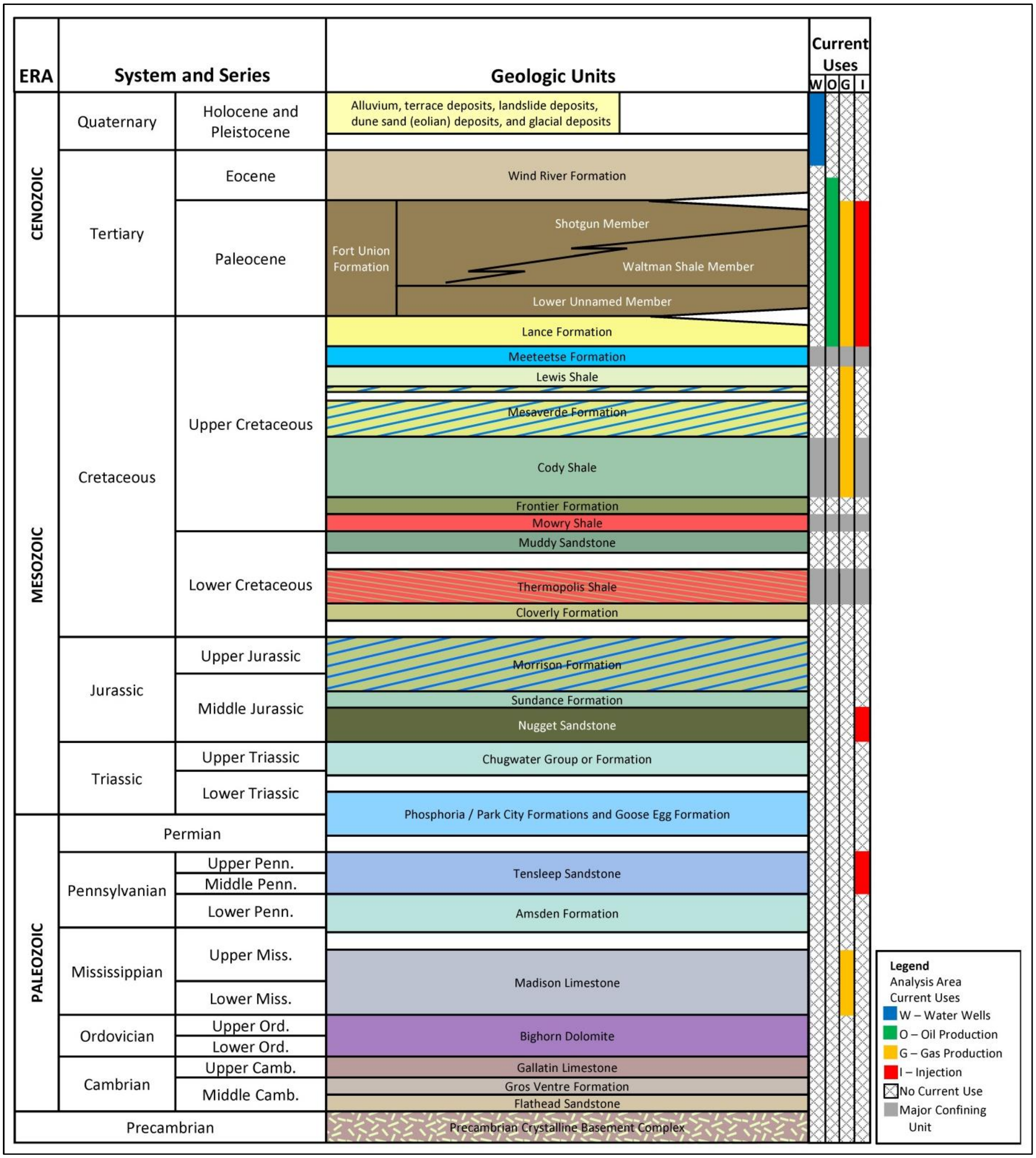
Groundwater in the analysis area occurs in aquifers of the Wind River geologic basin (Wind River basin). Geologists define the Wind River basin as the upper part of the Bighorn basin for surface water (Section 4.1, *Regional Overview*). The Wind River basin includes the analysis area plus upstream areas inside the Bighorn basin (Figure 1).

Groundwater occurs within aquifers that are separated by confining units. An aquifer is defined as a water-saturated hydrostratigraphic unit that contains sufficient permeability to yield water to a well or spring. A confining unit is defined as a hydrostratigraphic unit with very low permeability that impedes or precludes the movement of groundwater between aquifers.

Groundwater in the Wind River basin occurs in unconfined aquifers (Wind River and unconsolidated quaternary deposits) or within aquifers that are separated by confining units (Fort Union and deeper aquifers). In the analysis area, there are 12 named aquifers, seven named confining units, and two named units that contain both aquifers and confining units (WSGS 2012). The Wind River basin hydrostratigraphic units and their component geologic units are discussed in Section 5.1, *Hydrostratigraphic Units*.

Hydrostratigraphic units (aquifers and confining units) can be composed of a single geologic unit, part of a geologic unit, or multiple geologic units. Hydrostratigraphic units may not be separated, based on geologic unit boundaries, but rather on their hydraulic (permeability, recharge/discharge) characteristics. However, aquifers and confining units are typically named for the geologic unit(s) in which they predominantly occur (WSGS 2012). Figure 11 shows a stratigraphic column of the analysis area as it relates to current groundwater and oil and gas uses, and Figure 12 shows geologic cross-sections of the Wind River basin through the analysis area. Figure 13 shows cross-section locations on a surface geology map.

Figure 11. Stratigraphic Column of Analysis Area Showing Current Uses



Sources: USGS 2008; WSEO 2013; WSGS 2012; WOGCC 2014

Note: White areas in stratigraphic column show unconformities (buried erosional or non-depositional surfaces separating two rock masses or strata of different ages, indicating that sediment deposition was not continuous).

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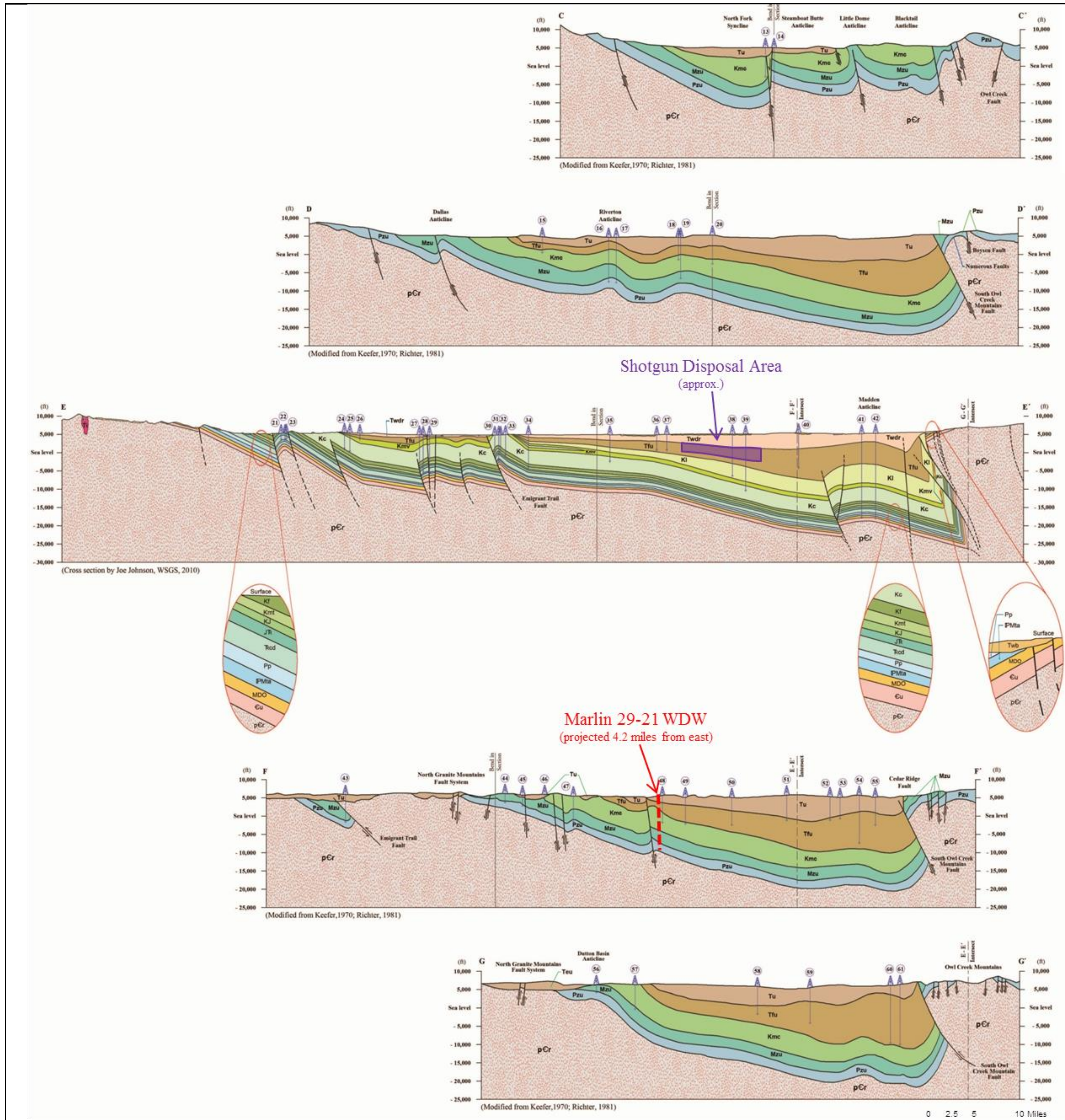
Figure 12. Geologic Cross-Sections through the Analysis Area in the Wind River Basin, Showing the Relative Depths of Hydrostratigraphic Units at the Center and Margins of the Basin



WELL CONTROL ALONG CROSS SECTIONS

Well No.	Api No.	Operator	Well Name	Bottom Formation
13	49-013-06468	British American Oil	Tribal Q 1	Cody
14	49-013-06469	Marathon Oil Company	Tribal C-14	Tensleep
15	49-013-05705	Atlantic Richfield Company	Federal-646-Fremont 2	Cody
16	49-013-05922	Devon Energy Production Company LP	Riverton Tribal 4	Tensleep
17	49-013-20261	Hudson Group LLC	Tribal 6	Wind River
18	49-013-06002	BP America Production Company	Shoshone 1	Cody
19	49-013-06004	Peak Wyoming Acquisitins LCC	Tribal 1	Morrison
20	49-013-06035	Farmers Union Exchange	Shoshone-Arapahoe 1	Cody
21	49-013-21383	Hrubetz Oil Company	Dallas-Federal 1-19	Tensleep
22	49-013-06936	Sunset Intrenational	Govt 29-4B	Tensleep
23	49-013-05367	Cabeen Exploration	Govt 1	Tensleep
24	49-013-21915	Sauer Bill Oil & Gas Company LLC	Sauer Ogle 1	Frontier
25	49-013-05490	Conoco Inc.	Govt 2	Morrison
26	49-013-22204	Phillips Petroleum Company	Corehole 2	Mesaverde
27	49-013-05623	Devon Energy Production Company LP	Beaver Creek Unit 10	Phosphoria
28	49-013-05639	Devon Energy Production Company LP	Beaver Creek Unit 55	Tensleep
29	49-013-05649	Devon Energy Production Company LP	Beaver Creek Unit 40	Cambrian
30	49-013-20381	Texaco Exploration & Prod.	Govt-P L Ackerman 1	Skull Creek
31	49-013-20334	Legacy Reserves Operating LP	Alkali Butte Unit 8	Madison
32	49-013-20547	Legacy Reserves Operating LP	Federal 1	Thermopolis
33	49-013-05903	M K M Oil Company	Hagood 1	Thermopolis
34	49-013-20184	Occidental	Govt-Campbell Ridge 1	Morrison
35	49-013-05997	Swepi LP	Conant Creek Unit 22-27	Cody
36	49-013-21347	ANR Production Company	Conant Creek Unit 1-6	Fort Union
37	49-013-21454	Amerada Hess Corporation	Federal 30-23	Fort Union
38	49-013-22427	Encana Oil and Gas USA Inc.	Riverbank Unit 1	Meeteetse
39	49-013-20845	Dome Petroleum Corporation	Moneta Unit 1-29	Shannon
40	49-013-21820	Noble Energy Inc.	State 44-36	Fort Union
41	49-013-21510	Burlington Resources Oil & Gas Company L	Bighorn 2-3	Gallatin
42	49-013-22127	Burlington Resources Oil & Gas Company L	Bighorn 8-35	Madison
43	49-013-05238	Carter Oil Company	Uint 1	Tensleep
44	49-013-05354	Fresno Exploration Company	Frexco 1	Tensleep
45	49-013-05475	BP America Production Company	USA-Cheney 1	Phosphoria
46	49-013-05539	Davis Oil Company	Govt-Grieve 1	Morrison
47	49-013-05631	Impire State Oil	State 2	Tensleep
48	49-013-05999	Edmiston Gladys	Govt 1	Cody
49	49-013-06017	Conoco Inc.	Love Ranch 1	Mesaverde
50	49-013-06068	Conoco Inc.	Squaw Butte Unit 14-4	Lance
51	49-013-06175	Conoco Inc.	Unit 11-1	Fort Union
52	49-013-06391	True Oil LLC	Garvin 1	Fort Union
53	49-013-06440	Chevron USA Inc.	Hugh Day 1	Wind River
54	49-013-06494	Atlantic Richfield Company	Lysite Unit 1	Cody
55	49-013-06504	Gulf Oil Corporation	Federal W-77311 1	Lance
56	49-013-05622	Morton & Caperton	Govt-Midland 1	Tensleep
57	49-013-05889	Davis Oil Company	Govt 1	Muddy
58	49-025-06038	Conoco Inc.	Squaw Butte Unit 23-3	Lance
59	49-013-06169	Encana Oil and Gas USA Inc.	Graham Unit 1	Fort Union
60	49-025-06484	Pure Oil	Unit 2-A	Cody
61	49-025-06565	Union Oil Co. of California	Badwater Unit 1	Mesaverde

EXPLANATION

CROSS SECTION SYMBOLS

Formation contact

Fault - Dashed where inferred; arrows indicate relative movement

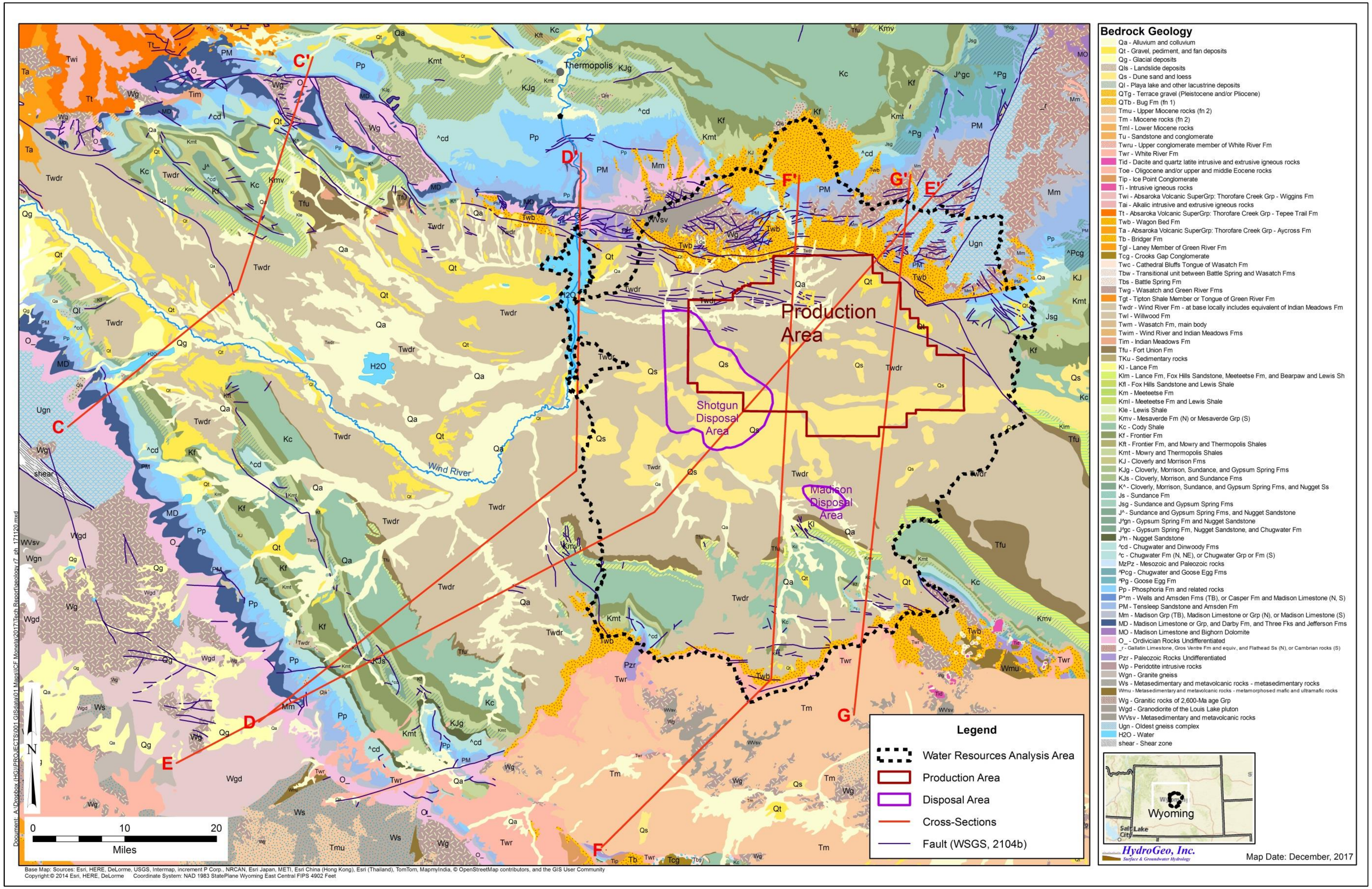
Drill hole - Well logs used to construct cross sections

GEOLOGY

Tu	Tertiary rocks undivided (Post-Fort Union Formation)
Tv	Tertiary volcanics
Ti	Tertiary intrusives
Teu	Lower Eocene and younger Tertiary rocks undivided
Twr	White River Formation
Twb	Wagon Bed Formation
Tta	Tatman Formation
Twdr	Wind River Formation
Twl	Willwood Formation
Tfu	Fort Union Formation
Mzu	Mesozoic rocks undivided
Kl	Lance Formation
Klm	Lance and Meeteetse Formations
Kme	Meeteetse Formation
Kml	Meeteetse Formation and Lewis Shale
Kmv	Mesaverde Formation
Kmc	Meeteetse and Mesaverde Formations and Cody Shale undivided
Kc	Cody Shale
Kf	Frontier Formation
Kfcv	Frontier Formation through Cloverly Group undivided
Kmr	Mowry Shale
Kmt	Mowry Shale, Muddy Sandstone, and Thermopolis Shale undivided
Kcv	Cloverly Formation
KJ	Cloverly and Morrison Formations undivided
Jm	Morrison Formation
Jm-Js	Morrison, Sundance and Gypsum Spring Formations
Jsg	Sundance and Gypsum Spring Formations
JTR	Sundance and Gypsum Spring Formations and Nugget Sandstone undivided
TRc	Chugwater Formation
TRcd	Chugwater and Dinwoody Formations
TRPu	Triassic and Permian rocks undivided
Pzu	Paleozoic rocks undivided
Pp	Phosphoria Formation
IPt	Tensleep Sandstone
IPMta	Tensleep Sandstone and Amsden Formation
IPad	Darwin Sandstone Member of Amsden Formation
Mm	Madison Limestone
MDmj	Madison Limestone, Jefferson, and Three Forks Formations
MDO	Mississippian, Devonian, and Ordovician units
Ob	Bighorn Dolomite
OЄbf	Bighorn Dolomite, Gallatin Limestone, Gros Ventre Formation, and Flathead Sandstone
Єu	Gallatin Limestone, Gros Ventre Formation, and Flathead Sandstone undivided
pЄr	Precambrian igneous and metamorphic rocks

Modified from WSGS 2012
Note: Cross section lines C-C', D-D', E-E', F-F' and G-G' are shown on Figure 13
Numbered circles represent wells.

Figure 13. Surface Geology Map with Cross-Section Locations



Source: WSGS 2012; WSGS 2014a; WSGS 2014b

Note: Cross-Sections C-C', D-D', E-E', F-F' and G-G' are shown on Figure 12

5.1 Hydrostratigraphic Units

5.1.1 Wind River and Quaternary Unconsolidated Deposit Aquifers

The Wind River Formation is exposed at the land surface or is directly below unconsolidated sediments across the entire analysis area (Figures 11 and 12). In the analysis area, all existing water wells are completed in the Wind River aquifer or in Quaternary unconsolidated sediments that lay on top of the Wind River aquifer (Table 22). The existing water wells in the analysis area are used for stock, monitoring, domestic, industrial, and irrigation purposes, and range in depth from 13 to 1,360 feet (Table 38). The Wind River and Quaternary unconsolidated aquifers are recharged from streams, irrigation diversions, and, to a lesser extent, precipitation (WSGS 2012). A limited amount of oil production occurs in the lower part of the Wind River Formation in the analysis area (Figure 11) (WOGCC 2014).

The Indian Meadows confining unit isolates the overlying Wind River aquifer from the underlying Fort Union-Lance aquifer and deeper hydrogeologic units. It can be up to 500 to 750 feet thick in parts of the Wind River basin but is not present across most of the analysis area (WSGS 2012).

5.1.2 Paleocene through Mississippian Hydrostratigraphic Units

In the analysis area, no water wells have been completed in any of the aquifers that lie stratigraphically below the Wind River Formation (Table 22), as they are considered too deep to be viable sources. Water well development does occur in these deeper aquifers but only outside of the analysis area at the edges of the Wind River basin, where they are closer to the surface (Figures 12 and 13) (WSGS 2012). The Madison aquifer, in particular, is an important water resource for the cities of Lander and Worland, Wyoming (WSGS 2012).

The Madison aquifer is a potential target for produced water disposal via injection in the Madison Disposal Area. Water samples from the Marlin 29-21 Test Water Disposal Well from the Madison Formation in the Madison Disposal Area have low total dissolved solids, averaging 1,100 milligrams per liter (mg/L) (WOGCC 2013). This indicates that even parts of the deep Madison aquifer may contain fresh water and may be hydraulically connected to a fresh water source.

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Table 22. Hydrostratigraphic Units in the Analysis Area and Their Current Uses

ERA	System and Series		Geologic Units		Lithology	Hydrostratigraphic Unit[1]	Aquifer Class	General Thickness in Wind River Basin	Comments	Estimated Transmissivity Range (ft^2/day) and Hydraulic Conductivity Range (ft/day)	Estimated Storage Coefficient (unitless)	Current (2012–2013) Uses in Analysis Area (ranked in order of predominance)	Current (August 2012 through July 2013) Produced Water in Analysis Area
CENOZOIC	Quaternary	Holocene and Pleistocene	Alluvium, terrace deposits, landslide deposits, dune sand (eolian) deposits, and glacial deposits		Sand and gravel interbedded with silt and clay with some coarser cobble and boulder deposits	Quaternary unconsolidated deposit aquifers	Major Aquifer - Alluvial	Generally < 50 ft, up to 200 ft	Important source of useable groundwater throughout the WRB, but limited continuity.	Transmissivity 9.6-162,000[1]	0.0001–0.001	(1) Water wells (stock, monitoring, and domestic)	--
	Tertiary	Eocene	Wind River Fm		Interbedded lenticular claystone, shale, siltstone, conglomerate, lenticular beds of fine- to coarse-grained sandstone. small amounts of bentonite, tuff, and limestone	Wind River aquifer	Major Aquifer – Sandstone	Up to 5,000 ft	Important source of useable groundwater throughout the WRB. Primarily intergranular permeability can be enhanced by fractures in deformed areas. Recharged from surface waters, irrigation, and precipitation.	Transmissivity 0.05-2,140[1] Hydraulic Conductivity 1 - 0.001	0.0001–0.002	(1) Water wells (stock, monitoring, domestic, industrial, and irrigation)	No
			Indian Meadows Fm		Variegated claystone, sandstone, and limestone	Indian Meadows confining unit	Major Confining Unit	Not Continuous in Analysis Area	Separates the overlying Wind River aquifer from the underlying Fort Union-Lance aquifer. Is not present across most of the Analysis Area.	ND	ND	--	--
		From this stratigraphic level hydrostratigraphic units become more deeply buried down-dip from outcrop areas along surrounding mountain ranges – Generally too deep for viable water resources except in and near outcrop areas – Generally confined to semiconfined except in outcrop areas of relatively limited extent compared to units exposed interior basin areas – Recharged from precipitation and streamflow on outcrop areas only											
		Paleocene	Fort Union Fm	Shotgun Member	Fine-to coarse-grained sandstone, conglomerate, siltstone, shale, carbonaceous shale, and coal	Fort Union aquifer	Minor Aquifer	2,200 feet to 2,830 feet	Important source of Oil and Gas in WRB. Shotgun Member of Fort Union Fm is target for injection in the Shotgun Disposal Area. Primarily intergranular permeability can be enhanced by fractures in deformed areas – Relatively low yield, variable hydrogeologic characteristics. None of the three members is present or recognized throughout the entire WRB.	Transmissivity 1.34[2] Hydraulic Conductivity 0.11 - 0.0001	ND	(1) Gas production (2) Oil production (3) Water disposal	Yes
				Waltman Shale Member	Organic-rich lacustrine shale with interbedded sandstone and siltstone			Up to and > 3,800ft (where present)		ND			
				Lower Unnamed Member	Interbedded conglomerate, fine-to, coarse-grained sandstone, gray shale, carbonaceous shale, and coal			<500 feet to <3,500 feet		Transmissivity 1.34[2] Hydraulic Conductivity 0.1 - 0.0001			
MESOZOIC	Cretaceous	Upper Cretaceous	Lance Fm		Sandstone interbedded with shale, claystone, siltstone, and thin coal	Lance aquifer	Minor Aquifer	<500 feet to <6,000 feet	With the exception of oil and gas wells, few wells have been installed in the aquifer.	2.2[1]	ND		
			Meeteetse Fm		Massive to thin bedded sandstone interbedded with shale, claystone, siltstone, mudstone, and occasional thin coal	Meeteetse– Lewis confining unit	Major Confining Unit	500 ft to >1,750 feet	Separates the overlying Fort Union–Lance aquifer from the underlying Mesaverde aquifer	ND	ND	--	--
			Lewis Shale		Shale								
			Mesaverde Fm		Variable sequence of massive lenticular fine- to coarse-grained sandstone, carbonaceous shale, and coal	Mesaverde aquifer	Minor Aquifer	500 ft to 2,200 ft	Oil and Gas Wells in WRB. Sandstones commonly function as distinct subaquifers – Intergranular permeability enhanced locally by fractures.	Transmissivity 3.9 (Drill Stem Test) 8.0-2,010 (Other Tests)[1]	ND	(1) Gas production (2) Water disposal	Yes
			Cody Shale		Marine shale with minor sandstone and siltstone	Cody confining unit	Major Confining Unit	3,250 to 5,500 ft	Regionally confines and separates the underlying lower and middle Mesozoic aquifers and confining units from the overlying Mesaverde aquifer.	Transmissivity 1.6-3.2 (Drill Stem Tests) 2.7-1,070 (Other Tests)[1]	ND	(1) Gas production	Yes
			Frontier Fm		Alternating sequence of very fine- to medium grained sandstone and shale	Frontier aquifer	Minor Aquifer	700 to 1,200 ft	Alternating sandstone and shale strata creates a series of subaquifers	Transmissivity 0.2-39.6 (Drill Stem Tests) 0.8-6,700 (Other Tests)[1]	ND	--	--

ERA	System and Series		Geologic Units	Lithology	Hydrostratigraphic Unit[1]	Aquifer Class	General Thickness in Wind River Basin	Comments	Estimated Transmissivity Range (ft^2/day) and Hydraulic Conductivity Range (ft/day)	Estimated Storage Coefficient (unitless)	Current (2012–2013) Uses in Analysis Area (ranked in order of predominance)	Current (August 2012 through July 2013) Produced Water in Analysis Area
MESOZOIC, CONTINUED	Cretaceous, continued	Upper Cretaceous, continued	Mowry Shale	Siliceous shale and bentonite	Mowry–Thermopolis confining unit	Major Confining Unit	395 to 560 ft	The thick Mowry–Thermopolis confining unit separates the underlying Cloverly aquifer from the overlying Frontier aquifer.	ND	ND	--	--
		Lower Cretaceous	Muddy Sandstone	Massive sandstone with interbedded mudstone		Minor Aquifer	20 to 134 ft		Transmissivity 0.04-0.7[1]	ND	--	--
			Thermopolis Shale	Shale and siltstone		Major Confining Unit	100 to 175 ft		ND	ND	--	--
			Cloverly Fm	Upper Dakota Sandstone interbedded with lenticular cherty pebble conglomerate and thin variegated shale, middle Fuson Shale, and lower basal fine- to coarse-grained Lakota Sandstone	Cloverly aquifer	Minor Aquifer	200 to 300 ft	Sandstones are subaquifers separated by leaky middle shale – Permeability is mostly secondary fractures highest in structurally deformed areas.	Transmissivity 2.4–78.2[1]	ND	--	--
	Jurassic	Upper Jurassic	Morrison Formation	Variegated claystone and shale with thin interbedded lenticular fine- to medium-grained friable sandstone	Morrison confining unit	Confining Unit and Minor Aquifer	300 to 570 ft	Generally low permeability, but interbedded sandstone lenses may have higher permeability.	Transmissivity 0.04–0.4[1]	ND	--	--
			Sundance Formation	Upper fine- to coarse-grained sandstone with thin shale and limestone interbeds, and a basal siltstone and sandstone grading downward into limestone, dolomite, and conglomerate	Sundance–Nugget aquifer	Minor Aquifer	200 to 900 ft	Intergranular permeability is locally enhanced by fractures. Nugget Sandstone is injection target in the Madison Disposal Area.	Transmissivity 6.0-19.4[2] Hydraulic Conductivity 0.01-0.001	ND	--	--
		Middle Jurassic	Nugget Sandstone	Upper fine- to medium-grained sandstone, a basal siltstone, mudstone, limestone, and thin to massive very fine-grained sandstone		Major Aquifer – Sandstone			Transmissivity 0.06-31.8[1] Hydraulic Conductivity 0.01-0.0001	ND	(1) Water disposal (test well)	--
	Triassic	Upper Triassic Lower Triassic	Chugwater Group or Fm	Siltstone, shale, silty sandstone, and hard, finely crystalline limestone	Chugwater–Dinwoody aquifer and confining unit	Marginal Aquifer & Confining Unit	0 to 460 ft	Minor Aquifers and Confining Units	Transmissivity 0.05-15.9[1] Hydraulic Conductivity 0.1-0.0001	ND	--	--
PALEOZOIC	Permian		Phosphoria / Park City Fms and Goose Egg Fm	Interbedded dolomite, chert, limestone, siltstone, fine-grained sandstone with phosphate beds/lenses and minor shale, shale and gypsum	Goose Egg–Phosphoria aquifer and confining unit	Minor Aquifer	Up to 600 ft		Transmissivity 0.05-8.6[1] Hydraulic Conductivity 0.1-0.0001	ND	--	--
	Pennsylvanian	Upper Penn. Middle Penn.	Tensleep Sandstone	Massive to cross-bedded, well-sorted, fine- to medium-grained sandstone cemented with carbonate and silica with thin layers of chert, limestone, and dolomite	Tensleep aquifer	Major Aquifer – Limestone	200 to 600 ft	Porosity and permeability is primarily intergranular dependent on the amount of secondary cementation and re-crystallization, both increasing with depth – Fractures and solution processes (in carbonate-rich zones) substantially enhances intergranular permeability in deformed areas. Injection target in the Madison Disposal Area.	Transmissivity 0.05–84.8[1] Hydraulic Conductivity 0.1-0.0001	ND	Water disposal (test well)	--
	Mississippian	**Lower Penn.** **Upper Miss.**	**Amsden Fm**	**Upper nonresistant shale, dense dolomite, thin cherty limestone, and thin, resistant, fine-grained sandstone; and a basal Darwin Sandstone Member of fine- to medium-grained, cross-bedded to massive, friable, porous sandstone**	Amsden aquifer	Marginal Aquifer	Up to 400 ft	The permeable parts of the Amsden Formation comprise the aquifer – Permeability of the Darwin is due to bedding plane joints and partings – Permeability of entire unit enhanced locally by fractures	Transmissivity 0.1–4.9[1] Hydraulic Conductivity 0.01-0.0001	ND	--	--

ERA	System and Series		Geologic Units	Lithology	Hydrostratigraphic Unit[1]	Aquifer Class	General Thickness in Wind River Basin	Comments	Estimated Transmissivity Range (ft^2/day) and Hydraulic Conductivity Range (ft/day)	Estimated Storage Coefficient (unitless)	Current (2012–2013) Uses in Analysis Area (ranked in order of predominance)	Current (August 2012 through July 2013) Produced Water in Analysis Area
	Mississippian **continued**	**Upper Miss. continued**	**Madison Limestone**	**Upper 100 feet of predominantly thin to massive limestone and dolomite, and a lower 500 to 600 feet of predominantly massive to thin-bedded crystalline limestone and dolomitic limestone**	Madison aquifer	Major Aquifer – Limestone	300 to 700 ft	Permeability is primarily secondary solution enhanced fractures, joints, and caverns mostly in the upper 1/3 of the aquifer – Primary permeability is not substantial in the dense, finely crystalline carbonates. Madison is injection target in the Madison Disposal Area	Transmissivity 0.1-1.2 (Drill Stem Tests) 12.3-80,400 (all other tests)[1] Hydraulic Conductivity 100-0.0001	0.00002-0.001	(1) Gas production	Yes
		Lower Miss.										
	Ordovician	Upper Ord.	Bighorn Dolomite	Upper Leigh Dolomite Member of dense, thin-bedded to massive dolomite, and the basal Lander Sandstone Member of fine- to medium-grained sandstone	Bighorn aquifer	Major Aquifer – Limestone	Up to 300 ft	Permeability in the Lander Sandstone Member is likely both primary (intergranular) and secondary (joints and fractures), permeability in the Leigh Dolomite is secondary	Transmissivity 670-1,100 (no drill stem tests avail.)[1] Hydraulic Conductivity 10-0.001	ND	--	--
		Lower Ord.										
	Cambrian	Upper Camb.	Gallatin Limestone	Thinly-bedded to massive glauconitic and oolitic limestone with interbedded shale, silty shale, and thin sandstone beds	Gallatin–Gros Ventre confining unit	Confining Unit	Up to 450 ft	Confines and separates the underlying Flathead aquifer from the overlying Paleozoic aquifer system	ND	ND	--	--
		Middle Camb.	Gros Ventre Fm	Limestone, shale, calcareous shale, with a flat-pebble conglomerate at the base			Up to 700 ft				--	--
			Flathead Sandstone	Fine-to medium-grained arkosic and quartzitic sandstone with some conglomerate and arkose in the lower part	Flathead aquifer	Minor Aquifer	50 to 200 ft	Primary permeability is intergranular, enhanced along partings between bedding planes and areas of local fracturing.	ND	ND	--	--
Precambrian			Precambrian Crystalline Basement Complex	Igneous and metamorphic Rocks	Precambrian basal confining unit	Major Confining Unit	Unknown	Nonporous. Permeability is from weathered regolith, and jointed and fractured crystalline bedrock.	ND	ND		

Source: WSGS 2012; Richter 1981; WOGCC 2014; WSEO 2013; USGS 2008
WRB = Wind River Basin; ft = feet; ft^2 = square feet
ND = No Available Data. Where no data are available, units will be assigned literature values (Heath 1983) for the representative rock type.
Hydraulic conductivity estimated from transmissivity.

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5.2 Groundwater Quality

The groundwater quality in the Wind River aquifer, including the analysis area, is highly variable. In general, for any given hydrogeological unit, water quality is best at or near the surface, where recharge occurs, and deteriorates with depth (WSGS 2012). TDS levels are generally elevated in the Quaternary alluvial aquifers and the upper Wind River aquifer, with median concentrations of 539 mg/L and 707 mg/L for non-produced (environmental) water samples, respectively (WSGS 2012). This compares to the secondary drinking water standard (the secondary standard is aesthetic and not health-related) (EPA 2012) of 500 mg/L (Table 23).

In Wyoming, groundwater quality standards are regulated by *Wyoming DEQ Water Quality Rules and Regulations,* Chapter 8, Quality Standards for Wyoming Groundwater (Wyoming DEQ 2005). Standards are different for drinking water (Class I) (EPA 2012), irrigation (Class II), livestock (Class III), fish and aquatic life (Class Special (A), industry (Class IV), hydrocarbon, mineral, or geothermal commercial (Class V), and unusable or unsuitable (Class VI) waters (Wyoming DEQ 2005). Refer to Attachment B for a complete table of Wyoming groundwater quality standards. Class I, II, and III groundwater quality standards for TDS and major cations and anions are shown in Table 23.

EPA regulates groundwater use with the Underground Injection Control program promulgated under Part C of the Safe Drinking Water Act (40 Code of Federal Regulations [CFR] 144). Waters that are or may be an underground source of drinking water are protected from any injection activity that could endanger the source. An underground source of drinking water is defined as:

> *"an aquifer or its portion: (a)(1) Which supplies any public water system; or (2) Which contains a sufficient quantity of ground water to supply a public water system; and (i) Currently supplies drinking water for human consumption; or (ii) Contains fewer than 10,000 mg/l total dissolved solids; and (b) Which is not an exempted aquifer. (40 CFR 144.3)"*

Water quality in the Quaternary unconsolidated deposit aquifers and the upper one-third of the Wind River aquifer is generally suitable for all uses, and water quality is very similar to the recharge source (surface water, irrigation channels, and/or precipitation) (WSGS 2012).

Shallow unconfined groundwater in the Quaternary unconsolidated deposits and Wind River aquifer is vulnerable to contamination from surface sources. A fall 2011 sampling round of 32 water wells in the analysis area noted the presence of volatile organic compounds and/or coliform bacteria in several samples. Methane was detected in six samples, diesel was detected in two samples, oil and grease were detected in one sample, and ethylene was detected in one sample. Total coliform bacteria were detected in 16 samples, fecal coliform bacteria were detected in one sample, and E.coli coliform bacteria were detected in four samples. The same sampling round also noted exceedances of Class I and Class III standards for copper, iron, lead, manganese, sulfate, pH, and gross alpha (TriHydro Corporation 2012).

Water quality data from the deeper two-thirds of the Wind River aquifer are from produced water samples. Produced water samples from deeper in the Wind River aquifer had a median TDS concentration of 2,730 mg/L, and concentrations were as high as 38,800 mg/L (Table 23) (WSGS 2012).

Table 23. Groundwater Quality Standards

Sample Origin/ Area	pH	TDS (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sodium (mg/L)	Bi-carbonate/ Alkalinity (mg/L) *	Chloride (mg/L)	Sulfate (mg/L)	Source
Water Quality Standards										
Secondary Drinking Water Standard (Aesthetic)	6.5-8.5	500						250	250	EPA 2012
Drinking Water Advisory Table: Health-based Value						20			500	EPA 2012
Drinking Water Advisory Table: Taste Threshold						30-60		230	250	EPA 2012
Aquatic Life Chronic Value	6.5-9							860		Wyoming DEQ 2013b
Underground Water Suitability: Domestic	6.5-8.5	500						250	250	Wyoming DEQ 2005
Underground Water Suitability: Agriculture	4.5-9.0	2,000						100	200	Wyoming DEQ 2005
Underground Water Suitability: Livestock	6.5-8.5	5,000						2,000	3,000	Wyoming DEQ 2005
Underground Water Suitability: Fish/Aquatic Life	6.5-9.0	500-2000								Wyoming DEQ 2005

Source: Wyoming DEQ 2005
Water quality standard criteria in this table are applicable to Class I, II, and III groundwater.
TDS = total dissolved solids; mg/L = milligrams per liter

In the Wind River basin, environmental groundwater samples from the Fort Union, Lance, Nugget, Tensleep, and Madison aquifers are predominantly from wells outside of the analysis area near the edges of the basin, where these aquifers are close to the surface (Figures 12 and 13). Thus, TDS levels in the environmental samples are much lower than in the produced water samples, which originate from areas where these aquifers are much deeper underground and where hydrocarbons are present.

In the Production Area and Disposal Area, these aquifers are very deep and have high TDS and salinity values. Groundwater in these aquifers is not considered to be a viable water resource, as it is too deep to be economically extracted (WSGS 2012). Additionally, due to the high salinity, the water would be unusable without treatment. An exception may be the Madison aquifer, which in three samples from the Marlin 29-21 Test Water Disposal Well in the Madison Disposal Area, shows moderate levels of TDS and salinity, with average TDS of 1,100 mg/L (Table 24) (WOGCC 2013).

A summary of available groundwater quality data in the analysis area is shown in Table 24. A full analysis of Wind River basin environmental and produced groundwater quality is presented in Wyoming State Geological Survey (2012). Detailed data are published by Wyoming Oil and Gas Conservation Commission (2014) and USGS (2014), where both data sources have large areas of overlap. TriHydro Corporation(2012) summarizes the results of the 2011 Production Area and Disposal Area environmental well water-sampling program.

A complete table of Wyoming Oil and Gas Conservation Commission produced water sample results from the Production Area and Disposal Area is presented in Attachment D.

Table 24. Groundwater Quality Summary

Sample Origin/ Area		pH	TDS (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sodium (mg/L)	Bicarbonate/ Alkalinity (mg/L) *	Chloride (mg/L)	Sulfate (mg/L)	Source
Shallow Aquifers											
Wind River Basin - Quaternary alluvial aquifer- Environmental Water	**Median**	**7.6**	**539**	**78**	**27**	**3**	**53**	**242***	**8**	**151**	WSGS 2012 Apdx E1
	Minimum	6.8	102	1	0	0	2	85.0*	0	3	
	Maximum	11.4	4,630	600	250	20	1,100	431*	105	2,600	
	# Samples	120	110	110	110	109	110	110*	110	110	
Wind River Basin - Aquifers in Quaternary sand dune (eolian) deposits - Environmental Water	**Median**	**8.5**	**833**	**22**	**9**	**5**	**230**	**175***	**8**	**440**	WSGS 2012 Apdx E1
	Minimum	--	--	--	--	--	--	--	--	--	
	Maximum	--	--	--	--	--	--	--	--	--	
	# Samples	1	1	1	1	1	1	1*	1	1	
Wind River Aquifer											
Production and Disposal Area - Produced Water (1 Well: 25 Graham)	**Average**	**8.8**	**1,086**	--	--	--	--	--	**20**	**439**	WOGCC 2014
	Minimum	--	--	--	--	--	--	--	--	--	
	Maximum	--	--	--	--	--	--	--	--	--	
	# Samples	1	1	--	--	--	--	--	1	1	
Production and Disposal Area - Environmental Water	**Average**	**8.38**	**1,388**	**39**	**12**	**3.0**	**439**	**237***	**19**	**877**	TriHydro 2012
	Minimum	7.47	260	1.7	0.27	<3	10	90*	4.3	44	
	Maximum	9.18	3,600	200	110	8.1	1,100	520*	68	2,700	
	# Samples	35	35	35	35	35	35	35*	35	35	
Wind River Basin - Produced Water	**Median**	**7.9**	**2,730**	**38**	**13**	**69**	**938**	**902**	**853**	**63**	WSGS 2012 Apdx F1
	Minimum	5.9	1,060	3	3	3	344	80	17	2	
	Maximum	8.2	4,860	135	30	115	1,610	1,200	1,180	658	
	# Samples	45	47	47	43	30	47	47	47	43	
Wind River Basin - Environmental Water	**Median**	**8.1**	**707**	**23**	**2**	**2**	**180**	**163***	**16**	**310**	WSGS 2012 Apdx E1
	Minimum	6.5	224	0.80	0.02	0.10	4.5	18.0*	3.0	3.2	
	Maximum	10	5,110	488	190	30	1,500	1,220*	693	3,250	
	# Samples	241	243	243	240	242	243	243*	243	243	

Sample Origin/ Area		pH	TDS (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sodium (mg/L)	Bicarbonate/ Alkalinity (mg/L) *	Chloride (mg/L)	Sulfate (mg/L)	Source
Fort Union and Lance Aquifers											
Production and Disposal Area - Produced Water from Fort Union and Lance aquifers (222 Wells)	**Average**	**7.7**	**9,945**	**243**	**36**	**165**	**3,491**	**2,631**	**4,347**	**55**	WOGCC 2014
	Minimum	1.01	441	1	1	2	167	110	8	1	
	Maximum	10.17	51,237	7,200	4,756	10,300	15,674	14,810	31,435	1,993	
	# Samples	320	324	317	291	254	322	305	323	250	
Wind River Basin, Fort Union aquifer - Produced Water	**Median**	**8**	**7,560**	**27**	**8**	**85**	**2,790**	**2,490**	**2,800**	**26**	WSGS 2012 Apdx F1
	Minimum	4.5	872	1	1	6	290	146	14	1	
	Maximum	10.2	69,100	18,400	680	27,900	20,700	14,800	43,000	6,820	
	# Samples	384	386	378	367	274	386	382	386	335	
Wind River Basin, Fort Union aquifer - Environmental Water	**Median**	**8.4**	**2,200**	**21**	**6**	**9**	**827**	**487***	**291**	**4**	WSGS 2012 Apdx E1
	Minimum	8.1	1,010	8	2	3	387	303*	270	1.5	
	Maximum	8.8	5,110	23	19	23	1,500	896*	780	3,100	
	# Samples	3	3	3	3	3	3	3*	3	3	
Wind River Basin; Lance aquifer Produced Water	**Median**	**8**	**6,720**	**33**	**9**	**29**	**2,580**	**2,000**	**2,680**	**101**	WSGS 2012 Apdx F1
	Minimum	5.8	1,680	4	1	7	689	122	152	4	
	Maximum	9.1	113,000	33,300	835	10,300	7,910	4,270	71,000	2,850	
	# Samples	80	80	80	77	34	80	80	80	71	
Nugget Aquifer											
Wind River Basin - Produced Water	**Median**	**7.9**	**6,520**	**194**	**30**	**77**	**2,010**	**376**	**636**	**3,090**	WSGS 2012 Apdx F1
	Minimum	5.80	1,200	10	3	5	370	60	36	91	
	Maximum	8.60	217,000	65,200	305	920	15,100	1,660	136,000	10,100	
	# Samples	33	34	34	33	15	34	34	34	34	
Wind River Basin - Environmental Water	**Median**	--	--	--	--	--	--	--	--	--	WSGS 2012 Apdx E1
	Minimum	7.2	272	50	16	1	12	219*	4	74	
	Maximum	7.5	1,470	77	25	6	400	295*	42	760	
	# Samples	2	2	2	2	2	2	2*	2	2	

Sample Origin/ Area		pH	TDS (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sodium (mg/L)	Bicarbonate/ Alkalinity (mg/L) *	Chloride (mg/L)	Sulfate (mg/L)	Source
Tensleep Aquifer											
Wind River Basin - Produced Water	**Median**	**7.7**	**2,930**	**248**	**56**	**51**	**611**	**500**	**210**	**1,300**	WSGS 2012 Apdx F1
	Minimum	5.20	167	16	4	10	9	92	4	3	
	Maximum	8.90	25,600	2,840	817	232	7,670	4,290	12,400	8,720	
	# Samples	89	114	114	110	16	114	113	113	113	
Wind River Basin - Environmental Water	**Median**	**7.6**	**208**	**42**	**21**	**3**	**4**	**175***	**4**	**22.5**	WSGS 2012 Apdx E1
	Minimum	6.8	146	31	14	1	2	108*	1	2.9	
	Maximum	8.5	1,060	158	40	7	93	530*	79	482	
	# Samples	13	15	15	15	14	15	15*	15	15	
Madison Aquifer											
Production and Disposal Area - Produced Water (2 Wells: 1-5 and 2-3 Big Horn)	**Average**	**5.4**	**597**	**17**	**1**	**6**	**177**	**146**	**312**	**17**	WOGCC 2014
	Minimum	5.40	370	10	1	4	110	138	170	9	
	Maximum	5.50	1,010	30	2	10	285	160	545	25	
	# Samples	3	3	3	3	3	3	3	3	3	
Madison Disposal Area	**Average**	--	1,100	--	--	--	--	--	--	--	WOGCC 2013
	# Samples	--	3	--	--	--	--	--	--	--	
Wind River Basin - Produced Water	**Median**	**7.7**	**2,040**	**165**	**28**	**43**	**499**	**299**	**470**	**576**	WSGS 2012 Apdx F1
	Minimum	5.7	291	32	4	3	2	90	4	29	
	Maximum	8.9	30,600	4,090	2,210	150	8,330	1,650	18,500	3,070	
	# Samples	62	64	64	64	38	64	62	64	64	
Wind River Basin - Environmental Water	**Median**	**7.8**	**216**	**45**	**22**	**2**	**4**	**192***	**4**	**17**	WSGS 2012 Apdx E1
	Minimum	7.1	181	33	12	1	2	104*	1	3.3	
	Maximum	8.1	920	180	34	8	79	502*	30	560	
	# Samples	14	13	13	13	13	13	13*	13	13	

* Values for alkalinity as $CaCO_3$, all others are bicarbonate

Samples – number of samples; TDS = total dissolved solids; mg/L = milligrams per liter

As part of the Water Management Plan for the Project (Encana 2013), untreated produced water from existing oil and gas operations was analyzed by a certified laboratory for several key constituents. These untreated produced water quality data are summarized in Table 25.

Table 25. Untreated Produced Water Analytical Averages for Key Constituents

Analyses	Average	Units	Analyses	Average	Units
General Parameters			***Dissolved Metals***		
Alkalinity as $CaCO_3$	3,000	mg/L	Aluminum	400	µg/L
Total Hardness as $CaCO_3$	100	mg/L	Arsenic	<2.5	µg/L
Major Ions			Beryllium	<1	µg/L
Ammonia	8	mg/L	Boron	15000	µg/L
Calcium	60	mg/L	Cadmium	<0.08	µg/L
Chloride	3,300	mg/L	Chromium	<0.5	µg/L
Fluoride	15	mg/L	Copper	2.5	µg/L
Magnesium	40	mg/L	Iron	130	µg/L
Nitrate	3	mg/L	Lead	15	µg/L
Potassium	25	mg/L	Manganese	50	µg/L
Sodium	3,000	mg/L	Mercury	<0.2	µg/L
Sulfate	15	mg/L	Nickel	<2.5	µg/L
Physical Properties			Silica	90000	µg/L
Conductivity	11,000	µS/cm	Silver	<0.5	µg/L
pH	7.5	SU	Strontium	<0.5	µg/L
Total dissolved solids (TDS)	7,500	mg/L	Thallium	<0.1	µg/L
Total suspended solids (TSS)	50	mg/L	Zinc	1000	µg/L
Turbidity	35	NTU	***Hydrocarbons***		
Temperature	< 100	F	Total petroleum hydrocarbon	10	mg/L
Pressure	20	psi	Benzene	15	mg/L
Total organic carbon	300	mg/L	Toluene	30	mg/L
Chemical oxygen demand	1,200	mg/L	Ethyl Benzene	2	mg/L
Biochemical oxygen demand	350	mg/L	Xylene	15	mg/L
Total Metals			Gasoline range organics	250	mg/L
Selenium	<0.5	µg/L	Diesel range organics	75	mg/L
Iron	2000	µg/L	Methanol	150	mg/L
Barium	10	mg/L			

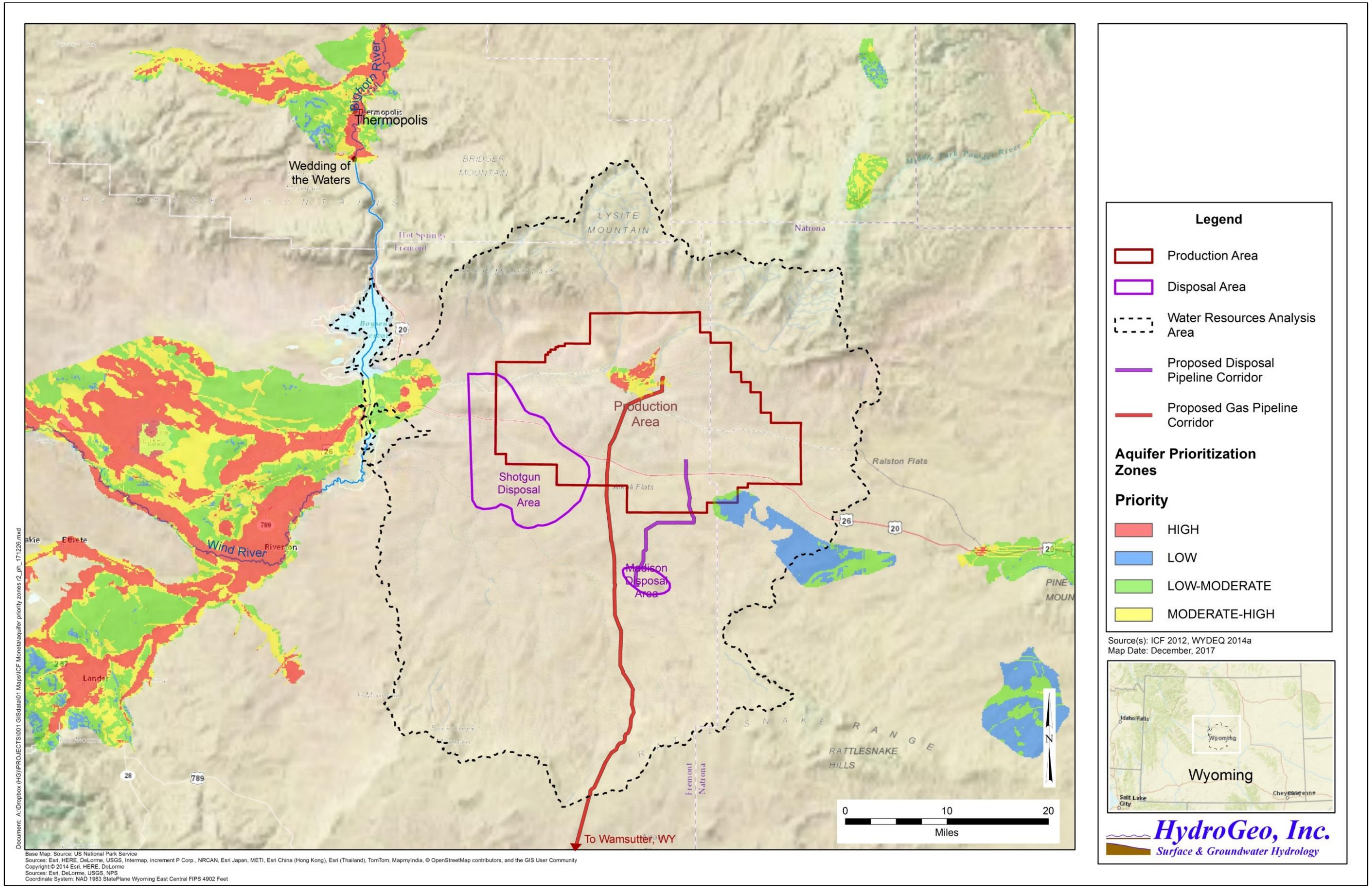
Source : Encana 2013
CaCO3 = calcium carbonate; mg/L = milligrams per liter; □/L = micrograms per liter = □S/cm = micrograms Siemens per centimeter; SU = standard unit; TDS = total dissolved solids; TSS = total suspended solids; NTU = nephelometric turbidity units; psi = pounds per square inch

5.2.1 High-Priority Aquifers

High-priority aquifers are specifically targeted for groundwater monitoring efforts. Aquifers that serve as drinking water sources and are most susceptible to point and nonpoint source pollution are designated as high-priority aquifers (Bedessem et al. 2005; Wyoming DEQ 2014).

The shallow alluvial aquifer underlying the areas of Lysite and Lost Cabin in the Production Area is designated as a high-priority aquifer. The aquifer in this area is less than 100 feet deep. Additionally, areas of the Wind River aquifer underlying Shoshoni, Bonneville, and the Municipal Airport near Shoshoni are designated as high-priority aquifers. The Wind River aquifer is between 250 and 1,100 feet deep at this location. The aquifer prioritization zones for ambient groundwater monitoring are shown on Figure 14. Existing groundwater rights are discussed in Section 6.2, *Groundwater Rights*.

Figure 14. Aquifer Prioritization Zones



Source: ICF 2012; Wyoming DEQ 2014

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5.3 Water Production and Water Disposal from Existing Oil and Gas Production

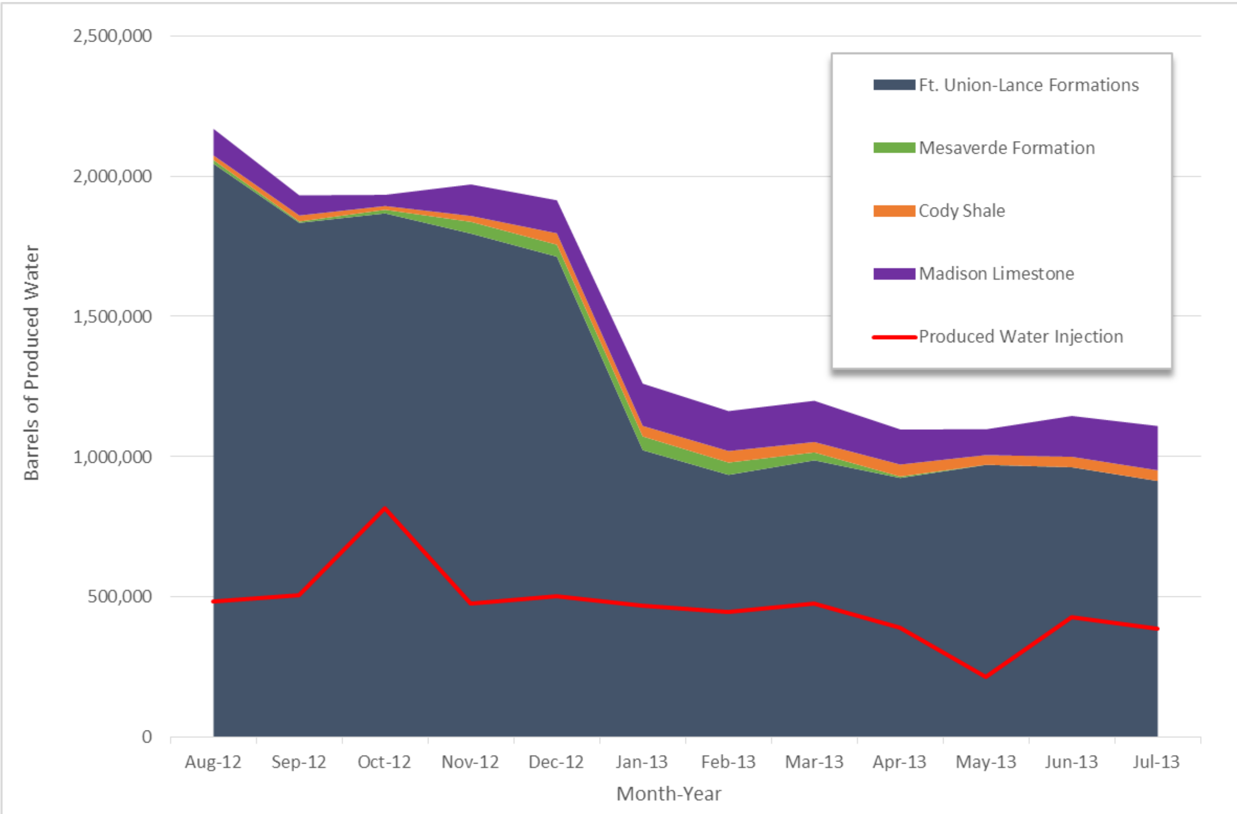
Groundwater is produced as a byproduct of oil and gas extraction. In the Production Area, from August 2012 through July 2013, water was produced from five stratigraphic horizons: the Wind River Formation, Fort Union-Lance Formations, Mesaverde Formation, Cody Shale, and Madison Limestone. The Fort Union-Lance Formations are the largest producers of oil and gas in the Production Area and are the largest producers of water. From August 2012 through September 2013, 18 million barrels of water were produced from 818 oil and gas wells in the Production Area. Thus, approximately 88 percent, or 16 million barrels of water, were produced from the Fort Union-Lance Formations (WOGCC 2014). The produced water data from oil and gas wells in the Production Area are summarized in Table 26 and illustrated in Figure 15. The locations of the oil and gas and disposal wells and Wyoming Pollution Discharge Elimination System (WYPDES) outfalls in the Production Area are shown on Figure 16.

Table 26. Produced Water in the Production Area (August 2012 through July 2013)

Producing Geologic Unit	Type of Production	Number of Oil- and/or Gas-producing Wells in Production Area (Aug. 2012 through July 2013)	Produced Water in the Production Area, 1 year total (Aug. 2012 through July 2013) (bbl)	Produced Water in the Production Area, 1 month total (July 2013) (bbl)
Wind River Formation	Oil	12	51	6
Fort. Union-Lance Formations	Oil, Gas	713	15,967,706	921,774
Mesaverde Formation	Gas	18	242,589	59
Cody Shale(1)	Oil, Gas	59	382,097	38,337
Frontier Formation	Gas	4	0	0
Muddy Sandstone	Gas	1	0	0
Phosphoria	Gas	2	0	0
Amsden Formation (Darwin Member)	Gas	1	0	0
Madison Limestone	Gas	8	1,397,724	157,738
Total	**--**	**818(2)**	**17,990,167**	**1,117,914**

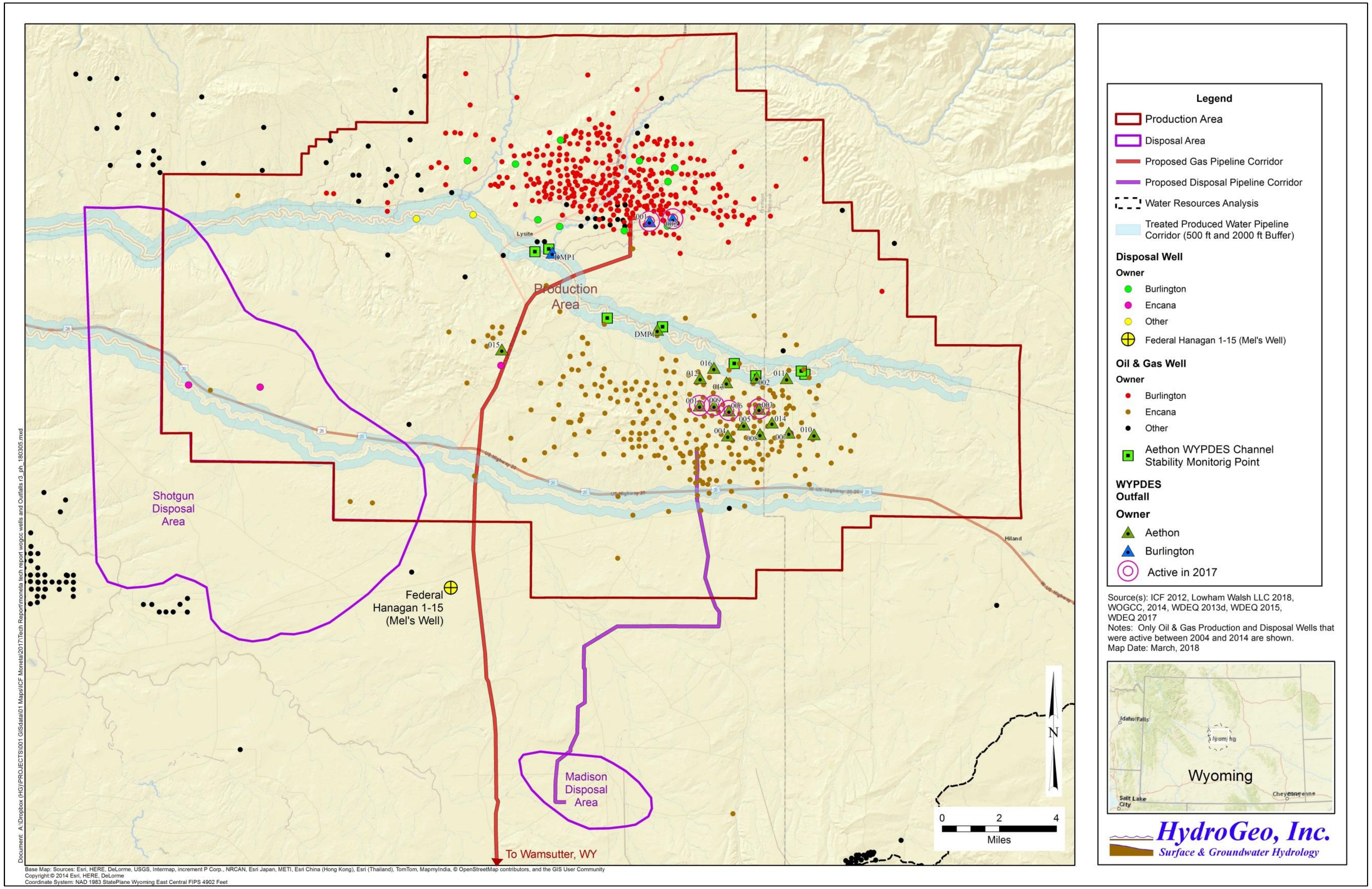
Source: WOGCC 2014
(1) Shannon and Sussex units are included with Cody Shale
(2) A limited number of wells produce from multiple stratigraphic horizons, so this number is higher than the actual total number of producing well locations in the analysis area
bbl = barrels, each with capacity of 42 US gallons

Figure 15. Total Monthly Produced Water and Produced Water Injection in the Production Area (Aug. 2012 - July 2013)



Source: WOGCC 2014
Note: Shannon and Sussex units are included with Cody Shale.
Wind River Formation produced water amount is too small to be visible at this scale.

Figure 16. Locations of Oil and Gas and Disposal Wells and Produced Water WYPDES Outfalls in the Production Area



Source: ICF 2012; Lowham Walsh LLC 2018; WOGCC 2014; Wyoming DEQ 2013d; Wyoming DEQ 2015; Wyoming DEQ 2017

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5.4 Produced Water Disposal via Injection

Deep disposal wells for wastewater produced as a byproduct of oil and gas production are classified as Class II Injection Wells in the Underground Injection Control Program established by Congress when it passed the Safe Drinking Water Act. According to the program, the Wyoming Oil and Gas Conservation Commission regulates Class II wells (Wyoming DEQ 2013c). Disposal well permits stipulate that the disposal operations will not endanger fresh water sources. Construction and monitoring standards for disposal wells are outlined by the commission (WOGCC 2010).

There are 22 active, abandoned, and currently proposed produced water disposal wells in the analysis area (2014). Of these, 14 wells were operational between August 2012 and July 2013. These 14 operational wells injected a total of 5.6 million barrels of produced water into the Fort Union and Lance formations. The injection volume data from August 2012 through July 2013 for the 14 operating wells in the analysis area are summarized in Table 27 and illustrated on Figure 15. The disposal well locations are shown on Figure 16.

Table 27. Produced Wastewater Disposal via Injection in the Analysis Area (2012 to 2013)

Well API #	Company	Formation	Aug. 2012 inj. (bbl)	Sep. 2012 inj. (bbl)	Oct. 2012 inj. (bbl)	Nov. 2012 inj. (bbl)	Dec. 2012 inj. (bbl)	Jan. 2013 inj. (bbl)	Feb. 2013 inj. (bbl)	Mar. 2013 inj. (bbl)	Apr. 2013 inj. (bbl)	May 2013 inj. (bbl)	June 2013 inj. (bbl)	July 2013 inj. (bbl)	Total inj. (bbl)
1320490	Burlington	Fort Union	26,122	19,724	56,487	22,964	26,015	29,834	29,715	26,936	16,901	18,481	4,269	0	**277,448**
1320661	Burlington	Lance	91,778	123,807	191,788	112,862	91,576	39,951	43,658	82,279	106,802	79,490	95,326	106,822	**1,166,139**
1320667	Burlington	Fort Union	76,823	67,256	77,502	51,048	66,728	65,514	70,757	68,940	68,463	45,294	65,398	65,800	**789,523**
1320680	Burlington	Lance	15,899	22,205	43,574	47,941	3,589	17,102	0	0	0	0	8,370	9,849	**168,529**
1320710	Moncrief	Fort Union	105	120	54	297	2,928	3,117	2,060	2,988	3,248	2,838	2,937	3,111	**23,803**
1320722	Burlington	Lance	6,727	4,008	26,187	18,084	11,383	22,306	25,102	20,608	5,996	4,972	2,631	3,154	**151,158**
1320895	Burlington	Fort Union	24,125	22,005	0	17,665	33,752	15,649	12,882	21,279	27,413	955	37,618	35,739	**249,082**
1321080	Burlington	Fort Union	124,121	148,185	275,858	120,192	135,108	129,017	138,382	146,550	86,180	1,480	113,671	73,125	**1,491,869**
1321211	Gas Ventures	Fort Union	7,851	6,935	6,500	6,969	4,704	1,487	5,802	4,353	3,622	6,105	10,788	10,534	**75,650**
1321483	Gas Ventures	Fort Union	1,889	1,031	1,000	107	48	156	142	126	145	472	445	304	**5,865**
1321924	Burlington	Lance	40,737	20,787	35,420	11,255	42,973	48,686	43,454	24,332	20,127	532	11,400	11,939	**311,642**
1321943	Burlington	Fort Union	13,875	15,738	17,474	5,682	12,847	21,328	19,913	7,433	0	0	13,579	13,779	**141,648**
1322209	Burlington	Fort Union	24,102	29,140	60,630	36,792	44,813	47,971	31,928	45,198	29,942	30,965	37,317	32,266	**451,064**
1322701	Encana	Fort Union	30,693	25,398	25,041	23,178	26,056	25,412	22,553	24,679	22,329	22,762	21,863	21,204	**291,168**
Total inj. (bbl)	--	--	**484,847**	**506,339**	**817,515**	**475,036**	**502,520**	**467,530**	**446,348**	**475,701**	**391,168**	**214,346**	**425,612**	**387,626**	**5,594,588**

Source: WOGCC 2014
inj. = injection; bbl = barrels, each with capacity of 42 US gallons

Additionally, there is one Class I disposal well in the analysis area, Federal Hanagan 1-15 (Mel's Well, operated by Mel's Water Service) (Figure 16). Class I injection wells are commercial disposal wells regulated by the Underground Injection Control Program. These wells inject industrial, municipal, and hazardous wastes. Mel's Well injects into the Lower Fort Union and Lance Formations. The groundwater in the Lower Fort Union Formation is classified as Class VI, which indicates it is unusable or unsuitable for use. The groundwater classification was based on the deep and remote location of the groundwater, which make extraction economically impractical, and the presence of hydrocarbons in the formation water. Injection at Mel's Well started in 1997. Injection volumes reached a maximum of 34,000 barrels per month in September 2006 and now average less than 15,000 barrels per month (WOGCC 2014).

5.5 Surface Water Discharge

5.5.1 Aethon WYPDES Permit WY0002062

Aethon has 16 permitted discharge locations under WYPDES permit WY0002062 (renewed by Wyoming DEQ in April 2015) on unnamed ephemeral tributaries to Alkali Creek (Wyoming DEQ 2015). However, not all of the discharge locations were active as of June 2017 (Figure 16). Total discharge per month for all the outfall locations between January 2011 and June 2017 ranged from about 27.3 to 84.9 million gallons per month (Table 28) (Wyoming DEQ 2017). While Alkali Creek and its tributaries are classified as ephemeral, the ongoing produced water discharges have created continuous flowing reaches in Alkali Creek and its tributaries (Wyoming DEQ 2017).

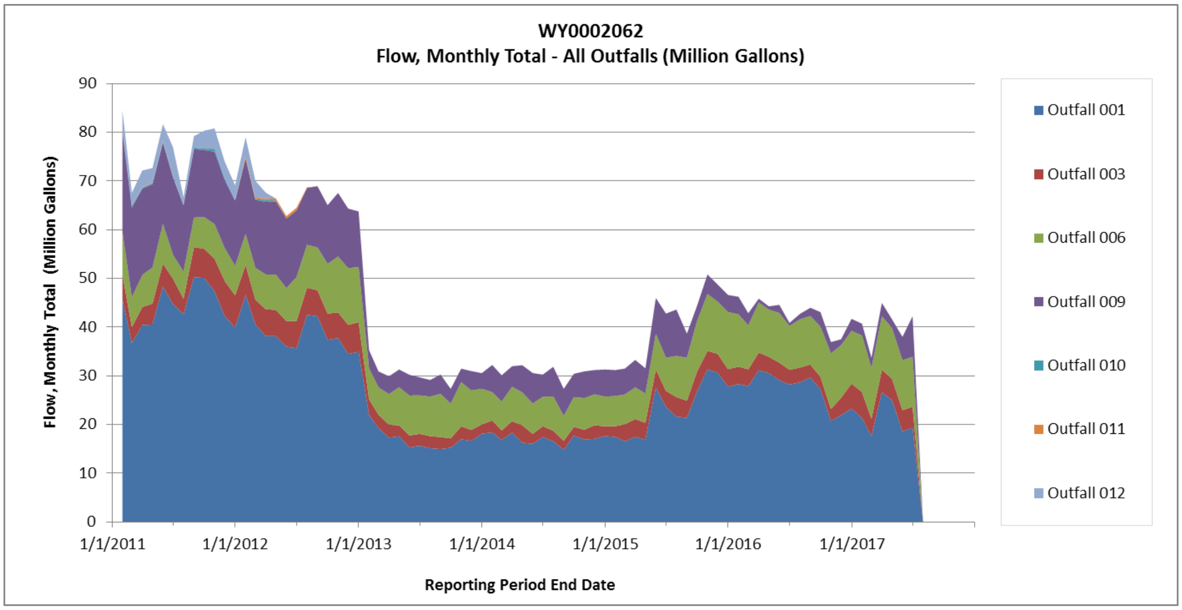
Between January 2011 and June 2017, Outfalls 001, 003, 006, 009, 010, 011, and 012 have had measurable discharges. Between April 2012 and June 2017, Outfalls 010, 011, and 012 have not had measurable discharges, and all measurable discharge has occurred in Outfalls 001, 003, 006, and 009. Between January 2011 and June 2017, the total combined monthly flow for all WYPED Permit WY0002062 outfalls ranged from about 84.9 million gallons (January 2011) to about 27.3 million gallons (August 2014) and averaged approximately 47.2 million gallons per month. (Table 28) (Figure 17) (Wyoming DEQ 2017).

Table 28. Aethon WYPDES Permit WY0002062 – Monthly Total Flow (Million Gallons) Summary (January 2011 through June 2017)

Outfall Number	Months with Reported Measurable Discharge (Jan 2011 - Jun 2017)	Average Monthly Total Flow (Million Gallons)	Max. Monthly Total Flow (Million Gallons)	Max. Monthly Total Flow Date	Min. Monthly Total Flow (Million Gallons)	Min. Monthly Total Flow Date	Total Monthly Total Flow (Million Gallons) (Jan 2011 - Jun 2017)
001	79	27.3	50.22	Aug-11	14.78	Aug-14	**2155.0**
002	0	--	0	--	0	Multiple	**0**
003	79	3.8	7.22	Nov-11	1.8	Sep-14	**298.2**
004	0	--	0	--	0	Multiple	**0**
005	0	--	0	--	0	Multiple	**0**
006	79	8.2	11.72	Dec-15	4.9	Jun-11	**647.4**
007	0	--	0	--	0	Multiple	**0**
008	0	--	0	--	0	Multiple	**0**
009	79	7.2	20.6	Jan-11	0.64	Jun-16	**572.1**
010	16	0.3	0.63	Oct-11	0	Multiple	**4.6**
011	7	0.4	0.54	Jun-11	0	Multiple	**2.7**
012	15	3.2	5.8	Jun-11	0	Multiple	**48.1**
013	0	--	0	--	0	Multiple	**0**
014	0	--	0	--	0	Multiple	**0**
015	0	--	0	--	0	Multiple	**0**
016	0	--	0	--	0	Multiple	**0**
Combined Total	**79**	**47.2**	**84.9**	**Jan-11**	**27.3**	**Aug-14**	**3728.1**

Source: Wyoming DEQ 2017

Figure 17. Aethon WYPDES Permit WY0002062 – Monthly Total Flow (Million Gallons)



Source: Wyoming DEQ 2015; Wyoming DEQ 2017

Aethon's discharge permit includes water quality criteria effluent limits for pH, oil and grease, dissolved zinc, and dissolved iron for all outfalls (001 through 016), and limits on specific conductance, chloride, and sulfate for Outfalls 013, 014, and 015 (Wyoming DEQ 2015) (Table 29). Additionally, the permit requires monitoring of total monthly flow and total sulfide concentrations at all outfalls, and monitoring of total sulfide and maximum and minimum daily pH at a designated downstream measuring point (DMP1) (Table 32), but no specific effluent limit is specified for these parameters.

The permit also includes the requirement to monitor channel stability and erosion at the point of discharge. Channel stability and erosion are an ongoing concern, as the discharge water flows through highly erodible soils (Oasis Environmental 2010). Aethon monitors stream channel evolution and stability along seven stream reaches (five assessment reaches downstream of permitted outfalls and two control reaches unaffected by discharge), and streamflow is monitored at six gaging stations (Figure 16). Channel stability monitoring reports are submitted to Wyoming DEQ on a quarterly basis (Lowham Walsh LLC 2018).

Discharge permit limits were established by Wyoming DEQ (2015). The original permit application, submitted prior to September 5, 1978, meets the criteria for beneficial use (Wyoming DEQ 2004). Therefore, based on *Wyoming DEQ Water Quality Rules and Regulations,* Chapter 2, Appendix H (c)(i) (2004), Wyoming DEQ allowed an exemption from discharge requirements for produced water discharges for existing Outfalls 001 through 012, and these are currently exempted from end-of-pipe effluent limits for chlorides, sulfates, and specific conductance. Permit limits for TDS for all outfalls and dissolved iron did not exist until 2013. Permit limits for chloride and specific conductance also went into effect in 2013; however, only for Outfalls 013, 014, and 015. Between January 1, 1999 and June 30, 2017, no discharge has been reported from Outfalls 007, 008, 013, 014, 015, or 016 (Table 29) (Wyoming DEQ 2017).

Table 29. Effluent Water Quality Limits for WYPDES Permit WY0002062

Outfalls	Effluent Characteristic	Daily Maximum
001 through-016	pH, standard units	6.5–9.0
	Oil and Grease, mg/L	10
	Dissolved Zinc, µg/L	118.1
	Dissolved Iron, µg/L	1,000
013, 014, and 015	Specific Conductance, µmhos/cm	7,500
	Chloride, mg/L	2,000
	Sulfate, mg/L	3,000
Sum of All Outfalls	Total Dissolved Solids, Tons per Month	908

Source: Wyoming DEQ 2015
mg/L = milligrams per liter; µg/L = micrograms per liter; µmhos/cm = micromhos per centimeter

In general, Aethon's WYPDES Permit WY0002062 discharge water has high concentrations of chloride and TDS and slightly alkaline pH values. Current water quality permit limits for the periods of record (variable) through June 2017 were exceeded in several instances (Wyoming DEQ 2017). The exceedances are summarized in Table 30 and shown in Figures 18 to 29. A complete table of the discharge monitoring report results for Aethon WYPDES Permit WY0002062 is presented in Attachment E.

From January 2011 through December 2012, the combined average TDS loads for all outfalls were 1,988 tons per month. Beginning in January 2013, discharge was decreased by shutting in some wells to bring TDS loads below the new permit limit of 908 tons per month (Figure 18). From April through August 2015, the permit effluent limit was temporarily increased to 1,760 tons per month to accommodate for testing and calibration of a new reverse osmosis water treatment unit (Wyoming DEQ 2015). From January 2013 through June 2017, the combined average monthly dissolved solid load for all outfalls was 864 tons per month. The combined average monthly TDS load for all outfalls (January 2011 through June 2017) was 1,202 tons per month (Table 31). Since January 2011, there have been zero exceedances of the combined TDS effluent permit limits (Figure 18). (Wyoming DEQ 2015; Wyoming DEQ 2017).

Table 30. Aethon WYPDES Permit WY0002062 Outfall Water Quality Summary

Analyte	Units	Effluent Limit	Count	# of ND	Average [2]	Max.	Max. Date	Max. Outfall Number	Min.	Min. Date	Min. Outfall Number	Period of Record	
												From	To
Dissolved Zinc (Inst. Max.)	µg/L	118.1	92	50	32	540	Dec-13	001	ND	Multiple	Multiple	Dec-13	Jun-17
Oil and Grease (Daily Max.)	mg/L	10	314	121	4.3	38.9	Dec-16	009	ND	Multiple	Multiple	Apr-02	Jun-17
pH (Inst. Max.)	SU	9.0	78	--	7.9	10.8	Jun-16	001	7.3	Jun-16	006	Dec-09	Jun-17
pH (Inst. Min.)	SU	6.0	78	--	7.5	8.5	Dec-09	009	3.8	Dec-16	001	Dec-09	Jun-17
Dissolved Iron (Inst. Max.)	µg/L	1,000	92	0	340	870	Jun-15	009	40	Dec-15	001	Dec-13	Jun-17
Chloride (Daily Max.)	mg/L	Variable[1]	90	0	2,193	5,200	Dec-12	009	431	Jun-16	001	Feb-04	Jun-17
Sulfate (Daily Max.)	mg/L	Variable[1]	59	18	9	107	Jun-16	001	ND	Multiple	Multiple	Jun-11	Jun-17
Specific Conductance (Daily Max.)	µS/cm	Variable[1]	354	0	9,839	16,700	Mar-11	001	860	Oct-15	001	Jan-11	Jun-17
Total Sulfide (as S) (Daily Max.)	µg/L	NA	92	58	628	6,000	Aug-16	009	ND	Multiple	Multiple	Dec-13	Jun-17

Source: Wyoming DEQ 2015; Wyoming DEQ 2017

(1) Outfalls 001 through 012 and 016 do not have effluent limits for chloride, sulfate, or specific conductance. Outfalls 013, 014, and 015 have daily maximum effluent limits of 2,000 mg/L for chloride, 3,000 mg/L for sulfate, and 7,500 µmhos/cm for specific conductance, but in the period of record no measurable discharge has occurred at these outfalls.

(2) ND – Non-detect. Non-detect values calculated as zero for averages.

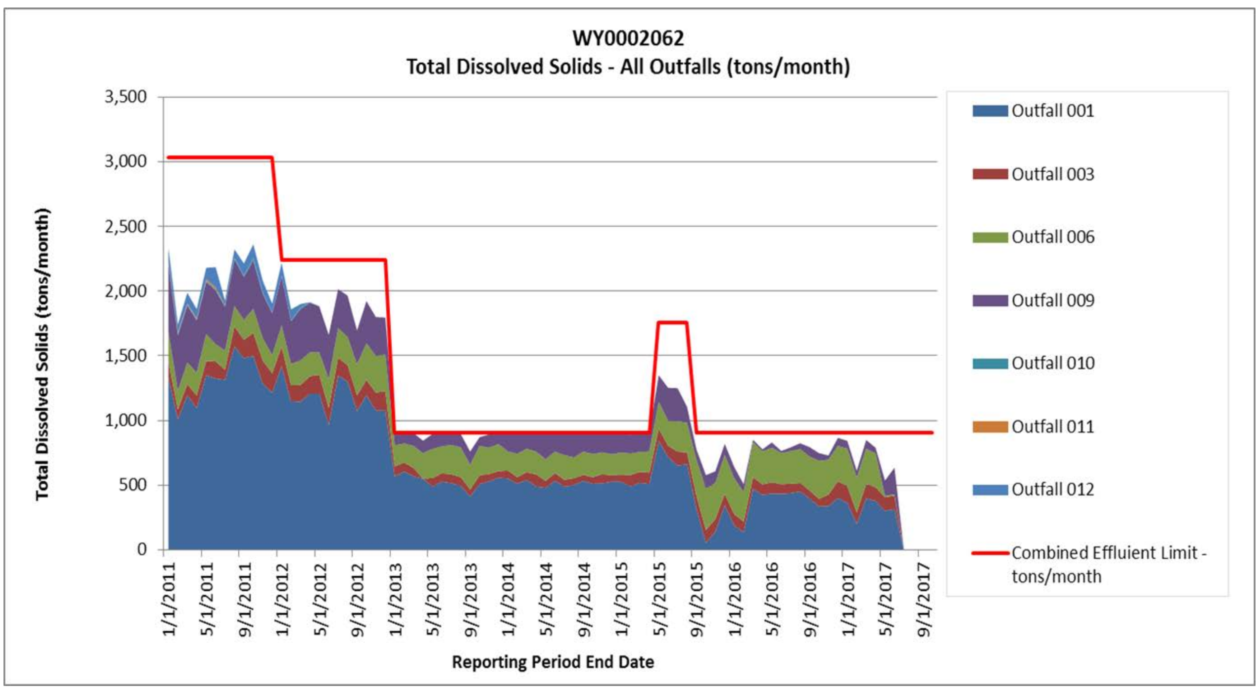
µg/L = micrograms per liter; mg/L = milligrams per liter; SU = standard unit; µS/cm = micrograms Siemens per centimeter

Table 31. Aethon WYPDES Permit WY0002062 –Total Dissolved Solids Summary (January 2011 – June 2017)

Outfall Number	Months with Measurable Discharge (Jan 2011 - Jun 2017)	Average TDS (tons/month)	Maximum TDS (tons/month)	Maximum TDS Date	Minimum TDS (tons/ month)	Minimum TDS Date	Total TDS (tons) (Jan 2011 - Jun 2017)
001	79	699	1,571	Aug-11	55	Oct-15	55,216
003	79	93	178	Oct-11	2.25	Apr-13	7,359
006	79	206	319	Oct-15	10.27	Jun-17	16,258
009	79	186	523	Jan-11	17	Apr-16	14,677
010	16	8	19	Oct-11	0	May-12	129
011	7	9	15	Jun-11	4	Jul-11	66
012	15	83	156	Jun-11	27	Mar-12	1,243
Combined Total	**79**	**1,202**	**2,362**	**Oct-11**	**509**	**Feb-16**	**94,948**

Source: Wyoming DEQ 2017
Non-detect values calculated as zero for averages.
TDS = total dissolved solids

Figure 18. Aethon WYPDES Permit WY0002062 –Total Dissolved Solids

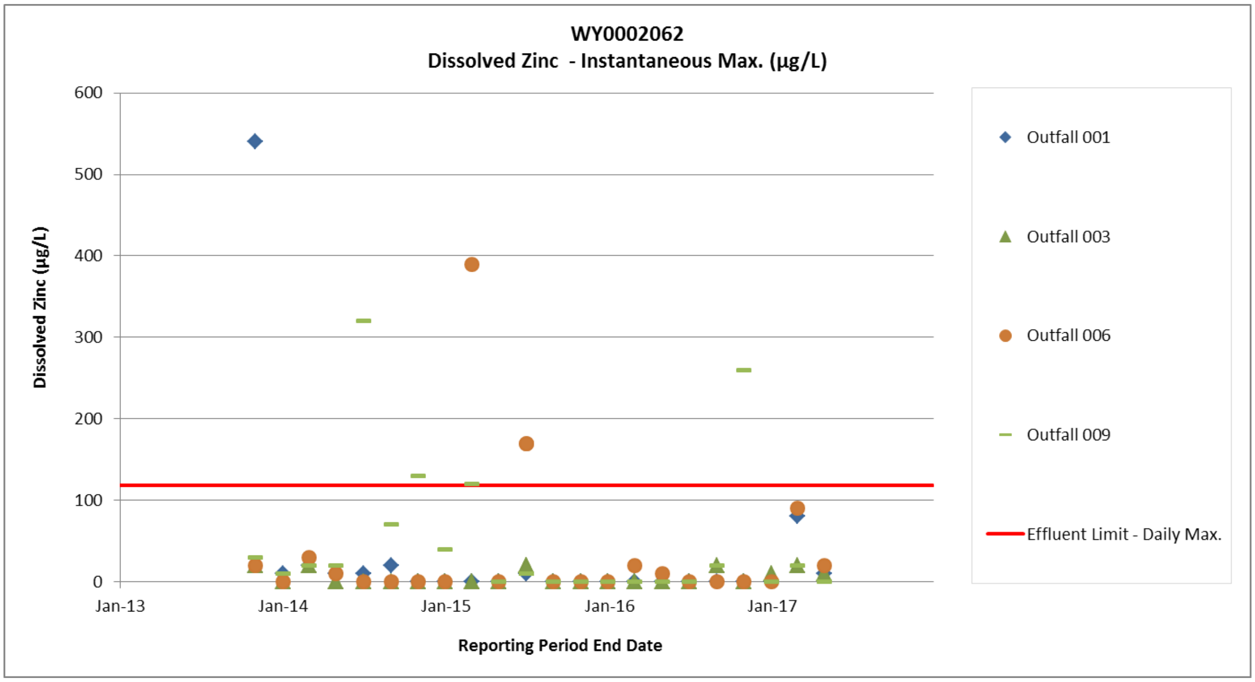


Source: Wyoming DEQ 2015; Wyoming DEQ 2017

Dissolved zinc concentrations for the period of record (December 2013 to June 2017) for WYPDES Permit WY0002062 are summarized in Table 30 and illustrated on Figure 19. For the period of record, the maximum measured dissolved zinc concentration was 540 micrograms per liter (µg/L), and the average discharge concentration was 32 µg/L. Several dissolved zinc concentrations were above the daily maximum effluent limit of 118.1 µg/L:

- Outfall 001 2013 (540 µg/L)
- Outfall 006 2015 (390, 170 µg/L)
- Outfall 009 2014 (320, 130, µg/L)
  2015 (120 µg/L)
  2016 (260 µg/L)

Figure 19. Aethon WYPDES Permit WY0002062 – Dissolved Zinc



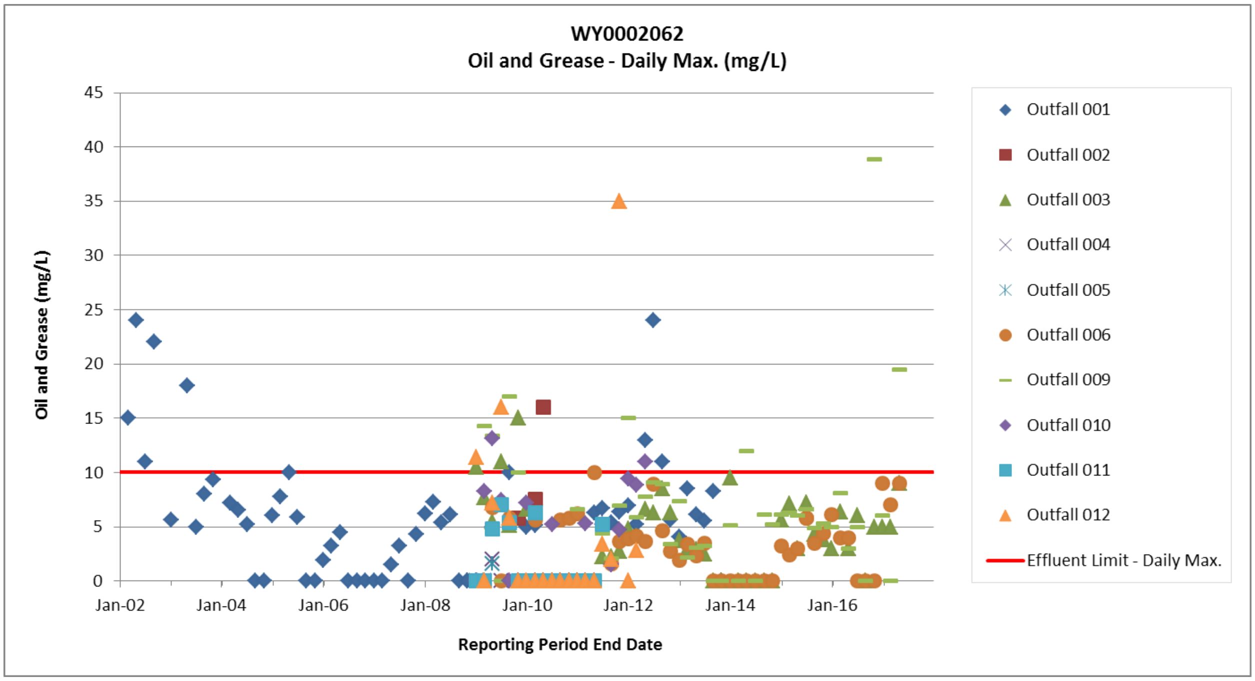
Source: Wyoming DEQ 2015; Wyoming DEQ 2017
Non-detect values graphed as zero.

Oil and grease concentrations for the period of record (April 2002 to June 2017) for WYPDES Permit WY0002062 are summarized in Table 30 and shown on Figure 20. For the period of record, the maximum measured oil and grease concentration was 38.9 mg/L, and the average discharge concentration was 4.3 mg/L. Several oil and grease concentrations for produced water were above the daily maximum effluent limit of 10 mg/L:

- Outfall 001 2002 (15, 24, 11, 22 mg/L)
  2003 (18 mg/L)
  2012 (13, 24, 11 mg/L)
  2014 (14, 24 mg/L)
- Outfall 002 2010 (16 mg/L)
- Outfall 003 2009 (10.5, 11, 15 mg/L)
- Outfall 009 2009 (14.3, 13.4, 17 mg/L)
  2012 mg/L)
  20132014 (12 mg/L)
  20168.9 mg/L)

- Outfall 010 — 20172017 (19.5 mg/L); 2009 (13.1 mg/L); 2012 (11 mg/L)
- Outfall 012 — 2009 (11.4, 16 mg/L); 2011 (35 mg/L)

Figure 20. Aethon WYPDES Permit WY0002062 – Oil and Grease



Source: Wyoming DEQ 2015; Wyoming DEQ 2017
Non-detect values graphed as zero.

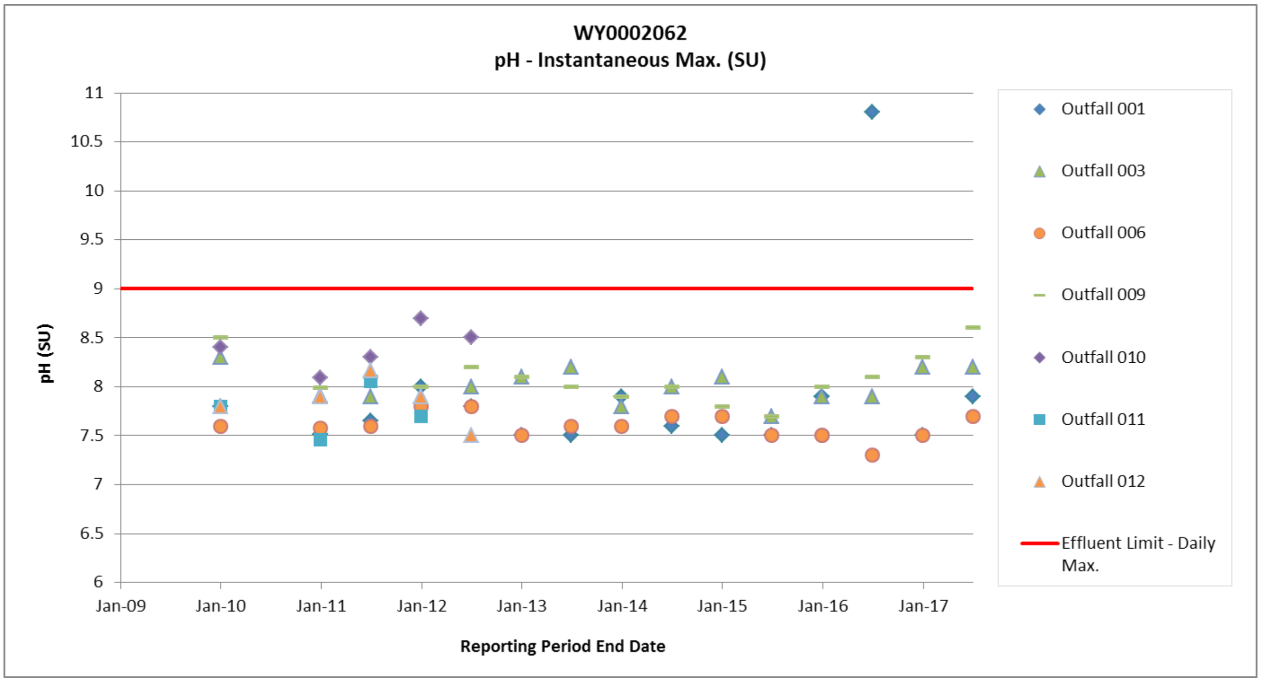
The pH values for the period of record (December 2009 to June 2017) for WYPDES Permit WY0002062 are summarized in Table 30 and shown on Figures 21 and 22. To date (June 30, 2017), there has been one exceedance for the daily maximum effluent pH permit limit of 9.0 standard unit (SU):

- Outfall 001 — 2016 (10.8 SU)

There was one exceedance of the daily minimum effluent pH permit limit of 6.0 SU through June 30, 2017 (Figure 22):

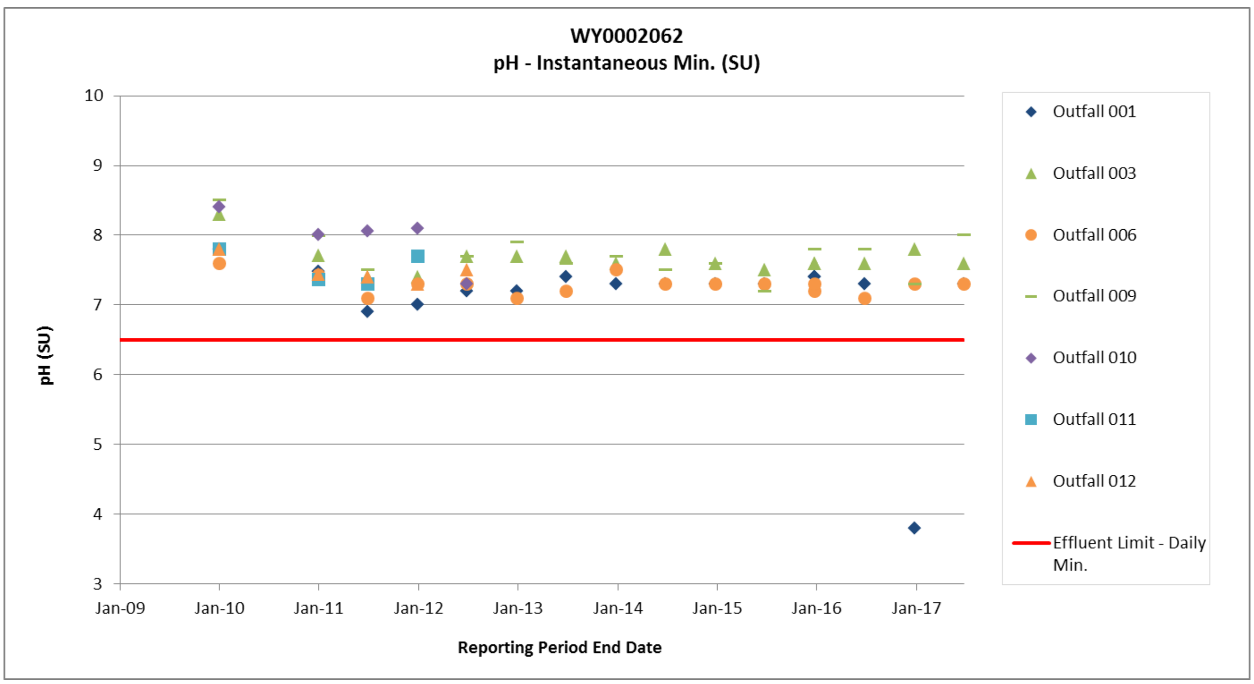
- Outfall 001 — 2016 (3.8 SU)

Figure 21. Aethon WYPDES Permit WY0002062 – Instantaneous Maximum pH



Source: Wyoming DEQ 2015; Wyoming DEQ 2017

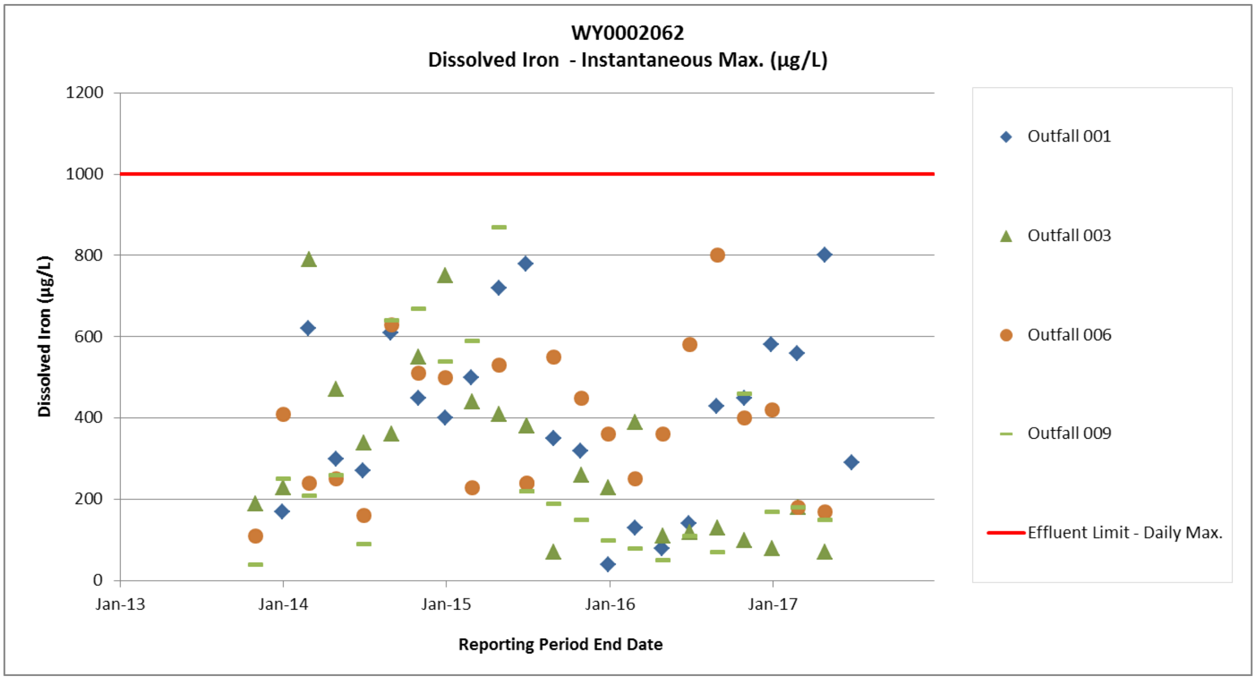
Figure 22. Aethon WYPDES Permit WY0002062 – Instantaneous Minimum pH



Source: Wyoming DEQ 2015; Wyoming DEQ 2017

Dissolved iron concentrations for the period of record (December 2013 to June 2017) for WYPDES Permit WY0002062 are summarized in Table 30 and shown on Figure 23. For the period of record, the maximum measured dissolved iron concentration was 870 µg/L, and the average discharge concentration was 340 µg/L. To date (June 30, 2017), there have been zero exceedances of the daily minimum effluent dissolved iron (permit limit 1,000 µg/L).

Figure 23. Aethon WYPDES Permit WY0002062 – Dissolved Iron

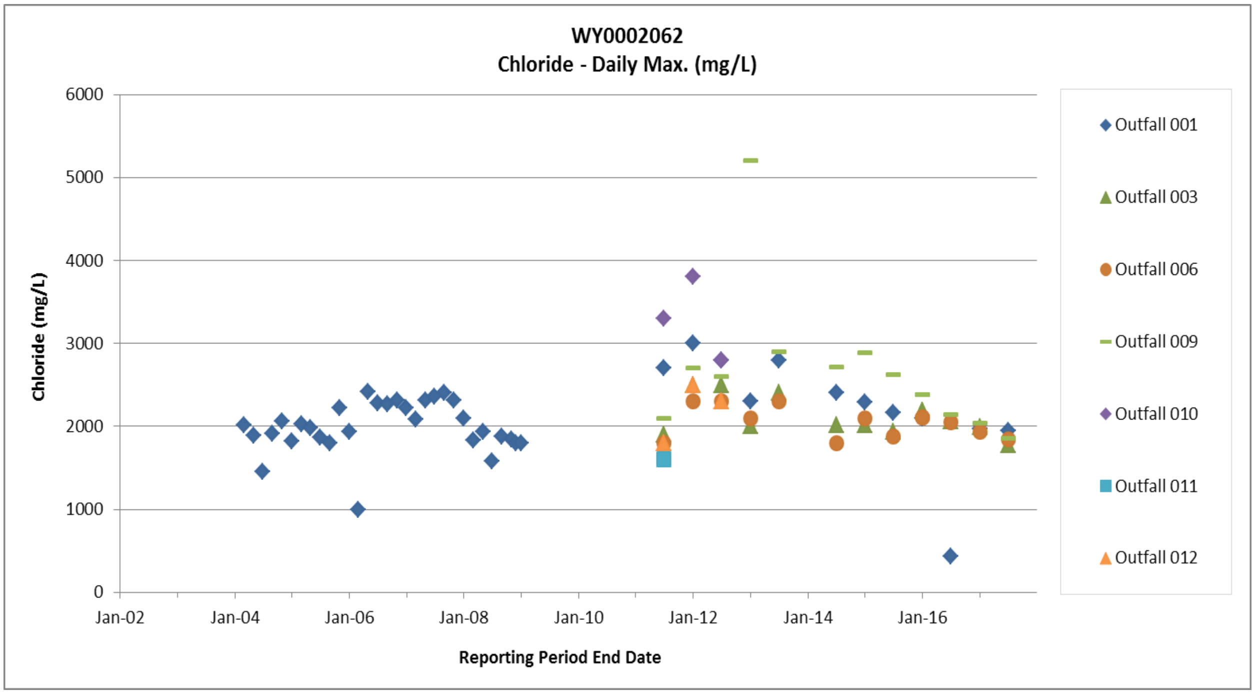


Source: Wyoming DEQ 2015; Wyoming DEQ 2017

Outfalls 001 through 012 and Outfall 016 do not have effluent limits for chloride, sulfate, or specific conductance. Outfalls 013, 014, and 015 have daily maximum effluent limits of 2,000 mg/L for chloride, 3,000 mg/L for sulfate, and 7,500 micromhos per centimeter (µmhos/cm) for specific conductance, but in the period of record, no measurable discharge has occurred at these outfalls.

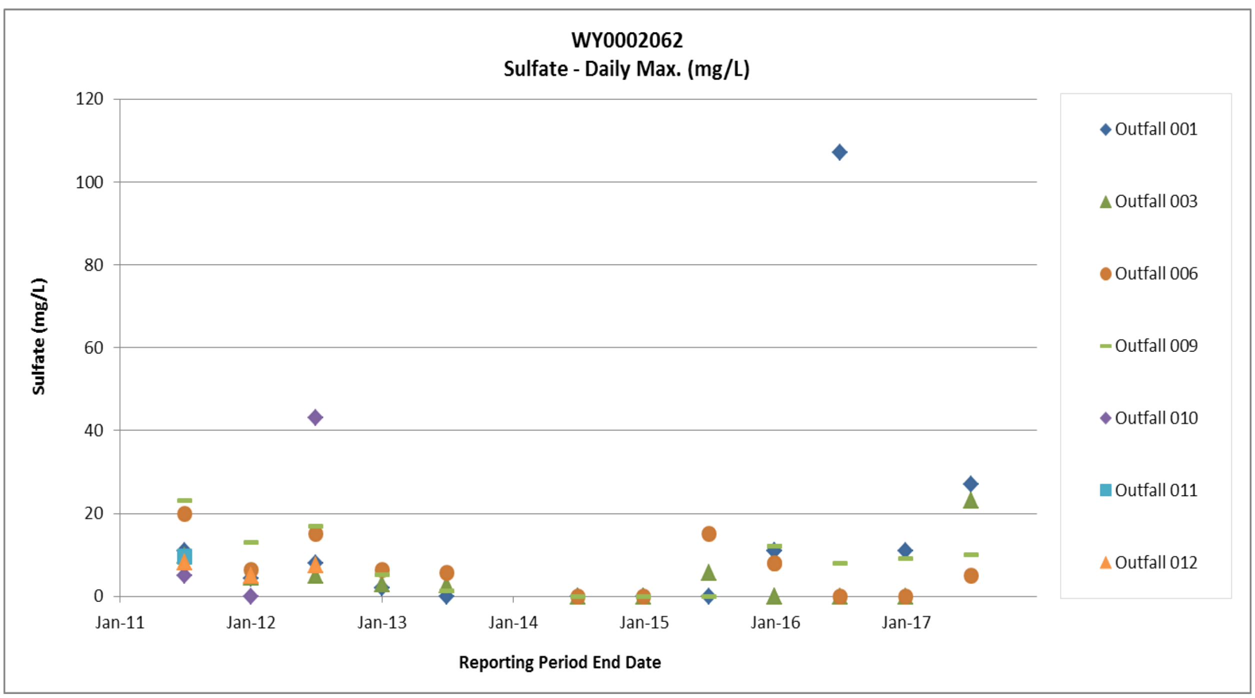
Chloride, sulfate, and specific conductance concentrations for WYPDES Permit WY0002062 are summarized in Table 30 and shown on Figures 24, 25, and 26, respectively. The average chloride concentration for the period of record (February 2004 to June 2017) for all outfalls was 2,193 mg/L. The average sulfate concentration for the period of record (June 2011 to June 2017) for all outfalls was 9 mg/L, and the average specific conductance for the period of record (January 2011 to June 2017) for all outfalls was 9,839 µmhos/cm.

Figure 24. Aethon WYPDES Permit WY0002062 – Chloride



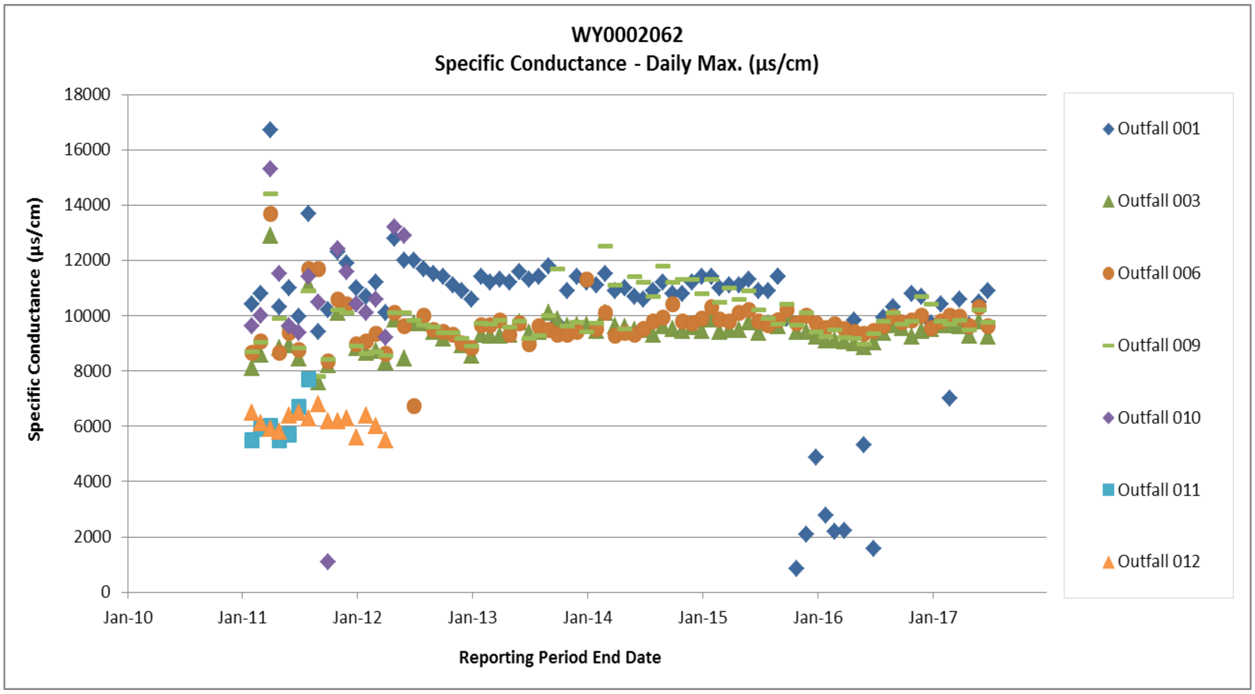
Source: Wyoming DEQ 2015; Wyoming DEQ 2017

Figure 25. Aethon WYPDES Discharge Permit WY0002062 – Sulfate



Source: Wyoming DEQ 2015; Wyoming DEQ 2017
Non-detect values graphed as zero.

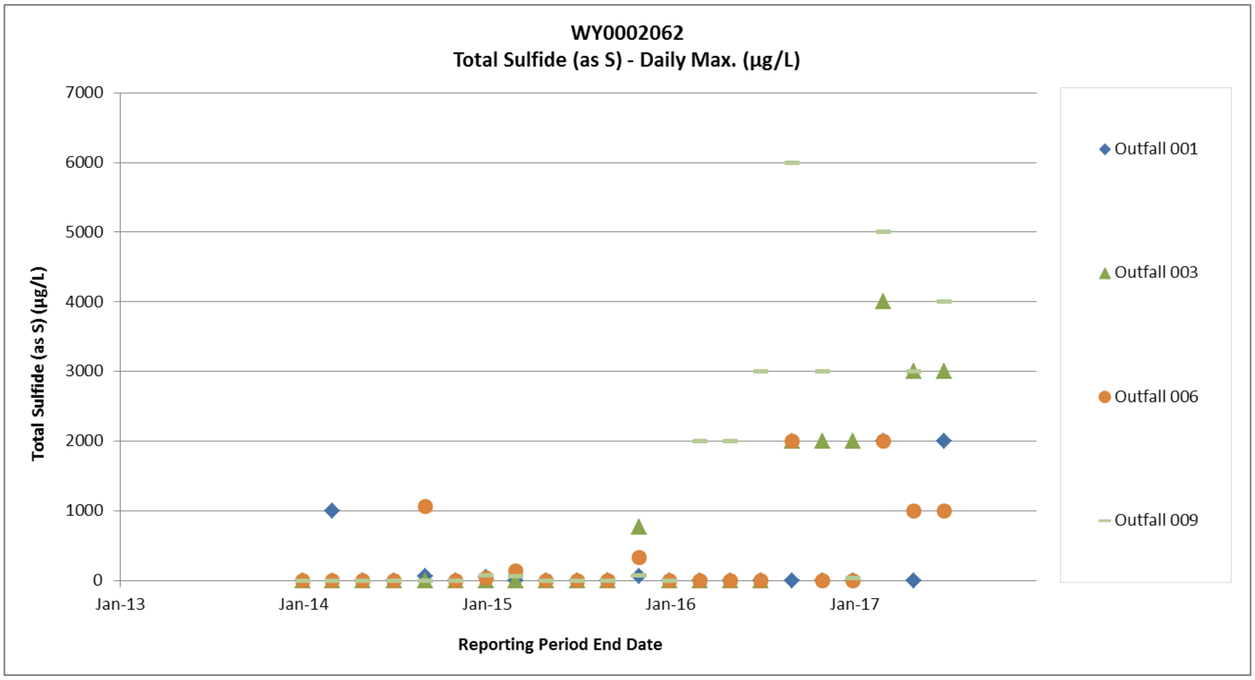
Figure 26. Aethon WYPDES Discharge Permit WY0002062 – Specific Conductance



Source: Wyoming DEQ 2015; Wyoming DEQ 2017

The permit requires measuring total sulfide at all outfalls once every 2 months, but there is not an effluent limit. Total sulfide concentrations for the period of record (December 2013 to June 2017) for WYPDES Permit WY0002062 are summarized in Table 30 and shown on Figure 27. The average total sulfide (S) concentration for the period of record for all outfalls is 628 µg/L.

Figure 27. Aethon WYPDES Discharge Permit WY0002062 – Total Sulfide (as S)



Source: Wyoming DEQ 2015; Wyoming DEQ 2017
Non-detect values graphed as zero.

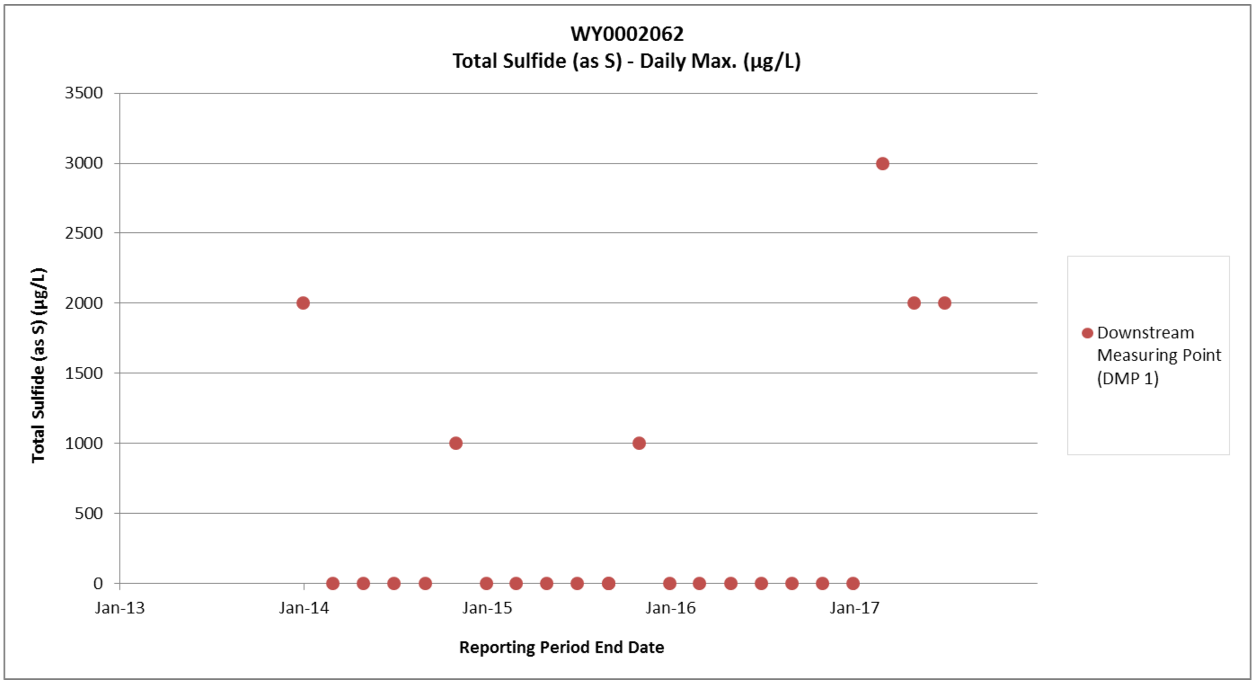
Monitoring of total sulfide (as S) and maximum and minimum instantaneous pH are required at a designated downstream measuring point (DMP1) (Figure 16). The water quality data for DMP1 are summarized in Table 32 and graphically illustrated in Figures 28 and 29. There are no effluent limits for these constituents.

Table 32. Aethon WYPDES Permit WY0002062 Downstream Measuring Point 1) Water Quality Summary

Analyte	Units	Count	# of ND	Average (1)	Max.	Max. Date	Min.	Min. Date	Period of Record	
									From	To
pH (Inst. Max.)	SU	29	--	8.8	9.28	Aug-09	8.27	Feb-14	Feb-09	Jun-17
pH (Inst. Min.)	SU	29	--	8.7	9.28	Aug-09	8.27	Feb-14	Feb-09	Jun-17
Total Sulfide (as S) (Daily Max.)	µg/L	23	17	478	3,000	Feb-17	ND	Multiple	Dec-13	Jun-17

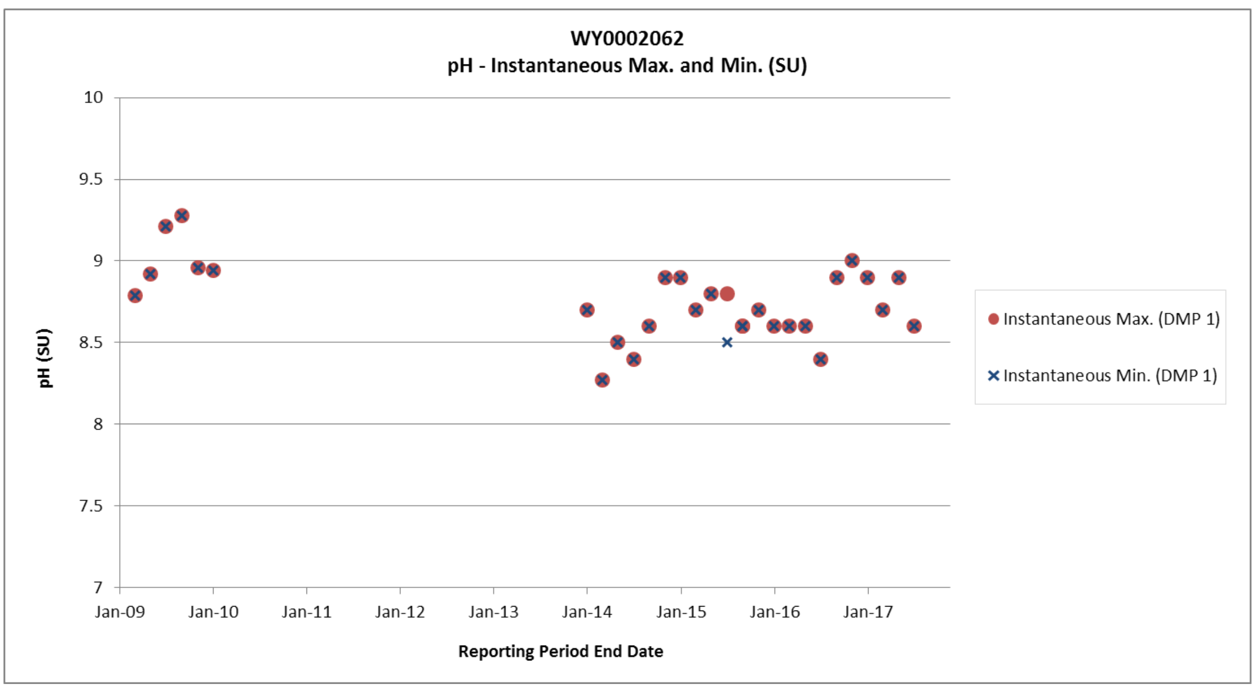
Source: Wyoming DEQ 2017
Non-detect values calculated as zero for averages.
ND = non-detect; SU = standard unit; µg/L – micrograms per liter

Figure 28. Aethon WYPDES Discharge Permit WY0002062 – Total Sulfide (as S) at Downstream Measuring Point (DMP 1)



Source: Wyoming DEQ 2015; Wyoming DEQ 2017
Non-detect values graphed as zero.

Figure 29. Aethon WYPDES Permit WY0002062 – Instantaneous Maximum and Minimum pH at Downstream Measuring Point (DMP 1)



Source: Wyoming DEQ 2015; Wyoming DEQ 2017

5.5.2 Burlington WYPDES Permit WY0036196

Burlington discharges produced water from its Lost Cabin Gas Plant into Sand Creek, an ephemeral tributary to Badwater Creek, via two outfalls (001, 002) (Figure 16), under WYPDES permit WY0036196 (Wyoming DEQ 2013d). Flows from Outfalls 001 and 002 are reported on a monthly basis. In Outfall 001 for the period of record (May 2002 to September 2017), monthly flows have ranged from zero (7 different months) to 136 million gallons per day (mgal/d) (April 2014) and averaged 3.35 mgal/d. In Outfall 002 for the period of record April 2003 to September 2017), monthly flows have ranged from 0 (36 different months) to 0.3 mgal/d (April 2006), and averaged 0.10 mgal/d. Flow data in Outfalls 001 and 002 are summarized in Table 33, and complete flow data for WYPDES permit WY0036196 are presented in Attachment E.

Table 33. Burlington WYPDES Permit W WY0036196 – Monthly Total Flow (mgal/d) Summary

Outfall Number	Period of Record		Months with Reported Measurable Discharge > 0 mgal/d	Months with No Reported Measurable Discharge	Average Flow (mgal/d)	Max. Flow (mgal/d)	Max. Flow Date
	From	To					
001	May-02	Sep-17	175	7	3.35	136	Apr-14
002	Apr-03	Sep-17	137	36	0.10	0.3	Apr-06

mgal/day = million galls per day

The permit does not allow discharge water to reach Badwater Creek. That is, the amount of discharged water must be small enough that all of the water infiltrates and/or evaporates before it reaches Badwater Creek. In order to ensure discharge water does not reach Badwater Creek, flow is measured at DMP1 (Figure 16) once every 2 months. If water reaches DMP 1, corrective action is implemented (Wyoming DEQ 2013d). Between May 2013 and September 2017, discharge water has reached the DMP1 in 2 of 47 months (October 2013 (0.10164 (mgal/d) and January 2014 (0.144 mgal/d) (Wyoming DEQ 2017).

Burlington's discharge permit includes limits for chemical oxygen demand, chloride, oil and grease, pH, phenols, specific conductance, sulfate, sulfide (total, as S), total chromium, and total recoverable radium 226 (Table 34). The permit also includes the requirement to monitor channel stability and erosion at the point of discharge. Channel stability and erosion are an ongoing concern, as the discharge water flows through highly erodible soils (HydroGeo 2015).

Table 34. Effluent Water Quality Limits for Burlington WYPDES Permit WY0036196

Effluent Characteristic	Daily Maximum	Monthly Average
Chemical Oxygen Demand, mg/L	120	80
Chloride, mg/L	2000	N/A
Oil and Grease, mg/L	10	N/A
pH, standard units*	6.5-9.0	N/A
Phenols, mg/L	0.1	0.05
Specific Conductance, micromhos/cm	7,500	N/A
Sulfate, mg/L	3000	N/A
Sulfide, Total (as S), mg/L	5	N/A
Total Chromium, mg/L	0.1	0.05
Total Recoverable Radium 226, pCi/L	60	N/A

Source: Wyoming DEQ 2013d

The water quality data for the period of record for WYPDES permit WY0036196 are summarized in Table 35, and a complete table of Discharge Monitoring Report data for the Permit is presented in Attachment E.

Current water quality permit limits for the period 2002 through September 2017 were exceeded in several instances (Wyoming DEQ 2017). The exceedances are noted below and the water quality data are graphically illustrated in Figures 30 to 43. There were no exceedances during the period of record for chloride, oil and grease, daily minimum pH, specific conductance, sulfate, or total recoverable radium 226 (Wyoming DEQ 2017).

Table 35. Burlington WYPDES Permit W WY0036196 – Water Quality Summary

Analyte	Units	Effluent Limit	Count	# of ND	Average (1)	Max.	Max. Date	Max. Outfall Number	Min.	Min. Date	Min. Outfall Number	Period of Record	
												From	To
Chemical Oxygen Demand (Daily Max.)	mg/L	120	107	2	51	280	Mar-08	001	ND	Sep-11	001, 002	Jun-02	Sep-17
Chemical Oxygen Demand (Monthly Avg.)	mg/L	80	107	2	41	118	Jun-06	001	ND	Sep-11	001, 002	Jun-02	Sep-17
Chloride (Daily Max.)	mg/L	2,000	18	0	49	180	Dec-13	001	5	Jun-17	001	Jun-13	Jun-17
Oil and Grease (Total Petroleum Hydrocarbons, Daily Max.)	mg/L	10	212	158	0.6	6.3	Jan-10	002	ND	Multiple	001, 002	May-02	Mar-13
pH (Inst. Max.)	SU	9.0	221	--	8.1	9.3	Jun-04	001	6.8	Dec-02	001	May-02	Jun-17
pH (Inst. Min.)	SU	6.5	221	--	7.7	8.74	Multiple	001	6.6	Jul-04	001	May-02	Jun-17
Phenols (Daily Max.)	mg/L	0.1	102	62	0.017	0.22	Dec-12	001	ND	Multiple	001, 002	Jun-03	Sep-17
Phenols (Monthly Avg.)	mg/L	0.05	102	62	0.015	0.22	Dec-12	001	ND	Multiple	001, 002	Jun-03	Sep-17
Specific Conductance (Daily Max.)	µS/cm	7,500	92	0	1,004	4,370	Dec-11	001	170	Jun-07	002	Jun-02	Jun-17
Sulfate (Daily Max.)	mg/L	3,000	18	0	80	120	Dec-14	001	44.4	Dec-16	002	Jun-13	Jun-17
Total Sulfide (as S) (Daily Max.)	mg/L	5	104	45	0.52	30	Jun-14	001	ND	Multiple	001, 002	Jun-02	Sep-17
Total Chromium (Daily Max.)	mg/L	0.1	105	64	0.008	0.1	Multiple	001, 002	ND	Multiple	001, 002	Jun-02	Sep-17
Total Chromium (Monthly Avg.)	mg/L	0.005	105	65	0.006	0.1	Sep-10	001	ND	Multiple	001, 002	Jun-02	Sep-17
Total Recoverable Radium 226	pCi/L	60	16	0	0.50	0.914	Dec-14	002	0.228	Dec-16	002	Dec-13	Jun-17

Source: Wyoming DEQ 2013d; Wyoming DEQ 2017

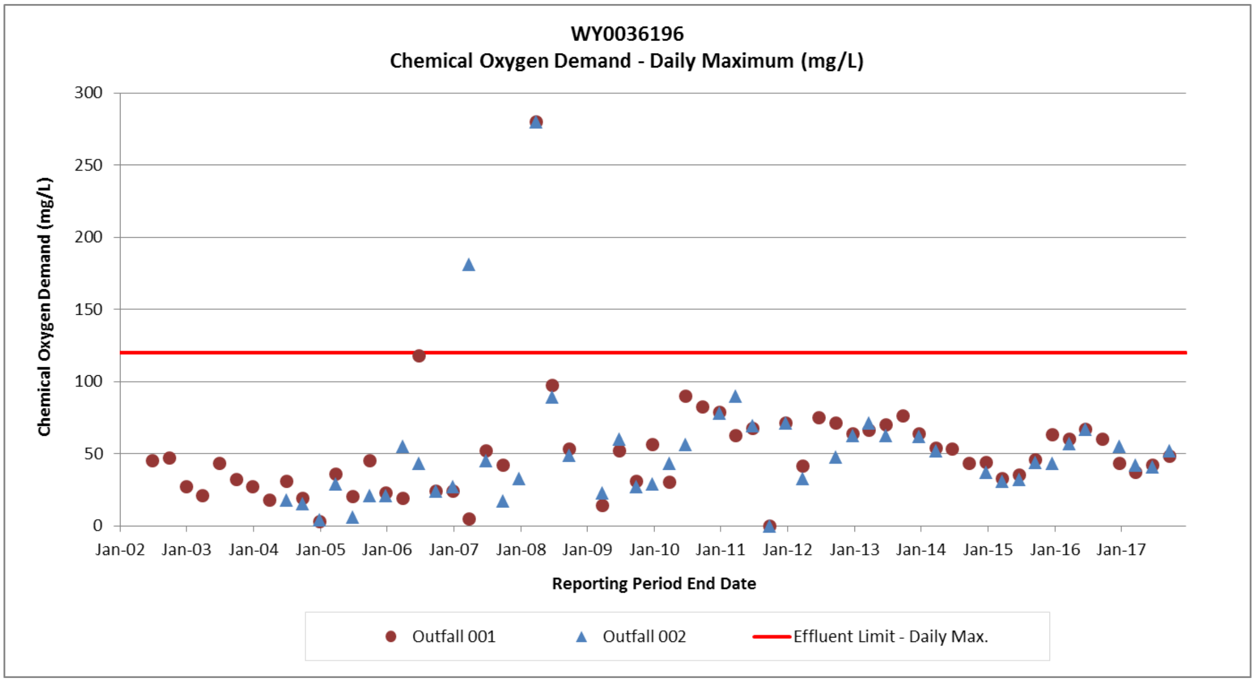
(1) Non-detect values calculated as zero for averages.

ND = non-detect; mg/L = milligrams per liter; SU = standard unit; µS/cm = micro-Siemens per centimeter; pCi/L = picocuries per liter

The daily maximum permit limit for chemical oxygen demand (120 mg/L) was exceeded on three occasions between 2002 and 2017 (Figure 30):

- Outfall 001 2008 (280 mg/L)
- Outfall 002 2007 (181 mg/L)
  2008 (280 mg/L)

Figure 30. Burlington WYPDES Permit WY0036196 – Daily Maximum Chemical Oxygen Demand

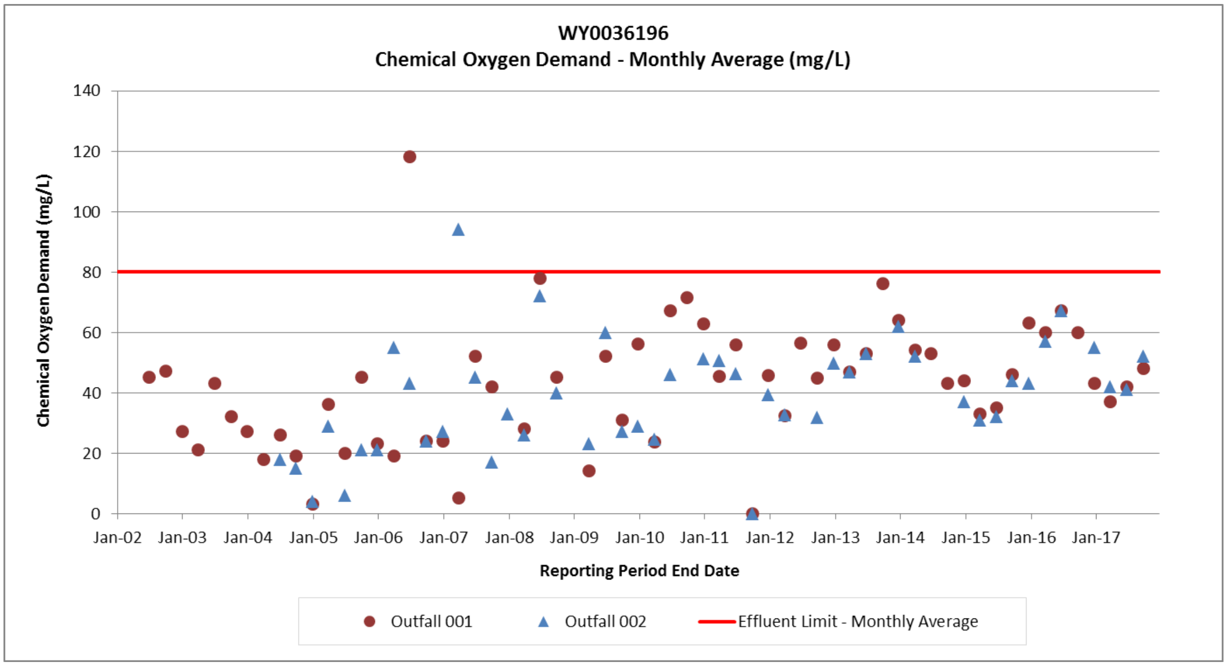


Source: Wyoming DEQ 2013d; Wyoming DEQ 2017
Non-detect values graphed as zero.

The monthly average permit limit for chemical oxygen demand (80 mg/L) was exceeded on two occasions (Figure 31):

- Outfall 001 2006 (118 mg/L)
- Outfall 002 2007 (94 mg/L)

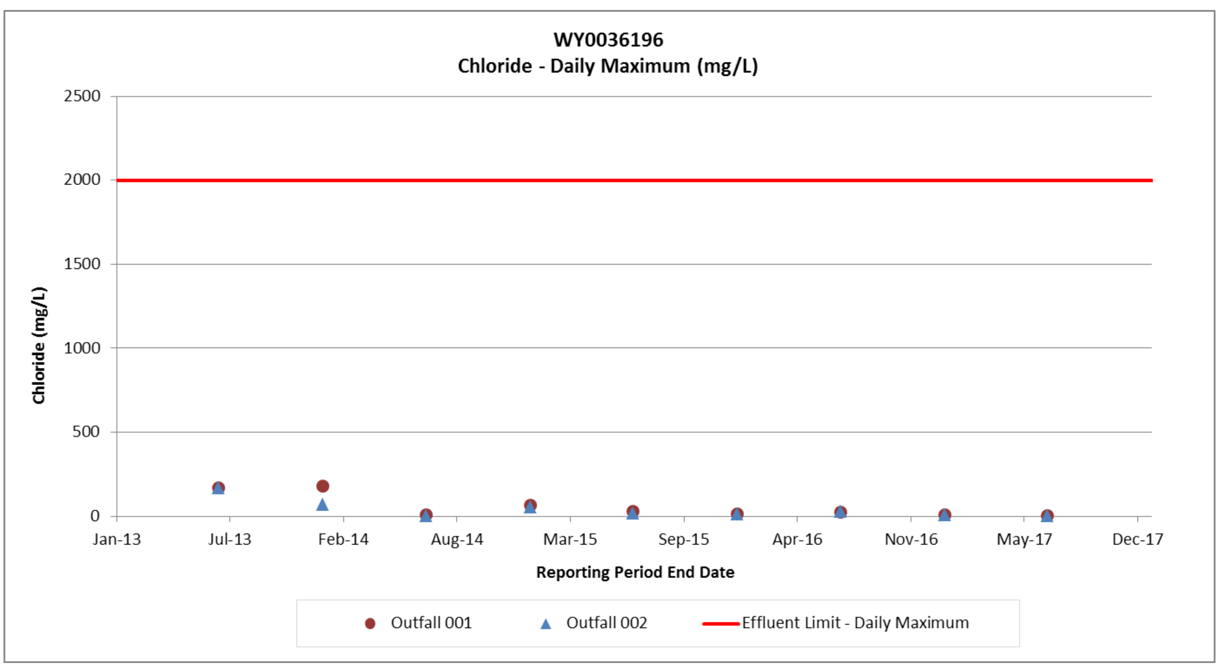
Figure 31. Burlington WYPDES Permit WY0036196 – Monthly Average Chemical Oxygen Demand



Source: Wyoming DEQ 2013d; Wyoming DEQ 2017
Non-detect values graphed as zero.

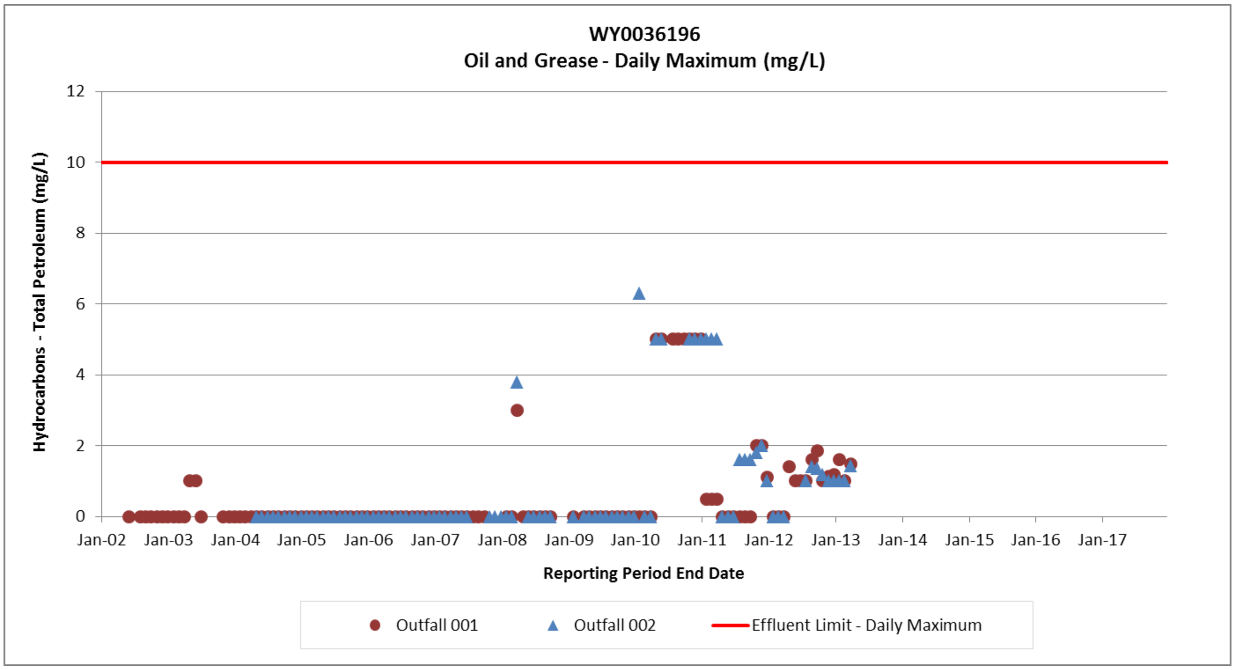
There were no permit exceedances during the period of record for chloride (2,000 mg/L) (Figure 32) or hydrocarbon –total (oil and grease) (10 mg/L) (Figure 33).

Figure 32. Burlington WYPDES Permit WY0036196 – Daily Maximum Chloride



Source: Wyoming DEQ 2013d; Wyoming DEQ 2017

Figure 33. Burlington WYPDES Permit WY0036196 – Daily Maximum Oil and Grease



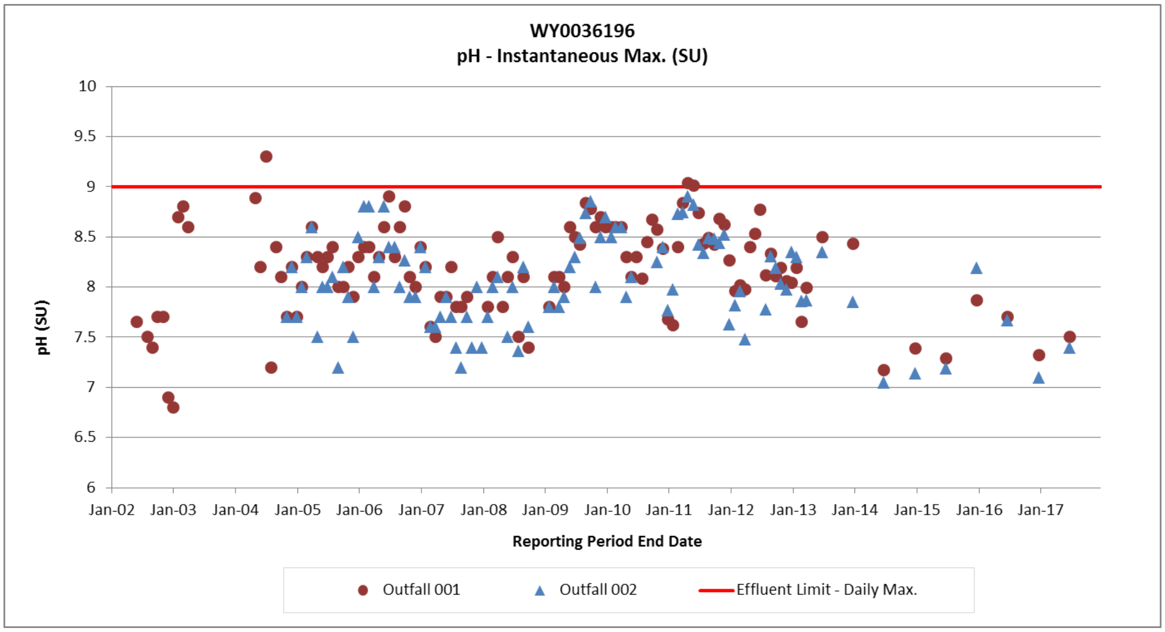
Source: Wyoming DEQ 2013d; Wyoming DEQ 2017
Non-detect values graphed as zero.

The daily maximum permit limit for pH (9.0 SU) was exceeded on three occasions between 2002 and 2017 (Figure 34):

- Outfall 001 2004 (9.3 SU)
  2011 (9.04 SU, 9.01 SU)

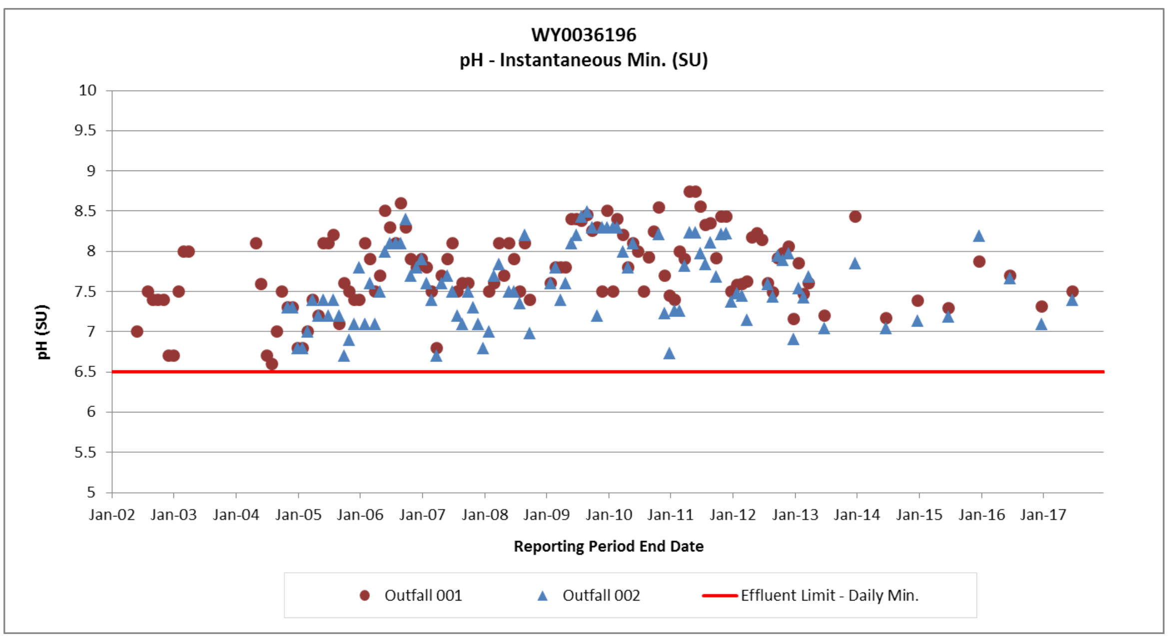
There were no exceedances during the period of record for daily minimum pH (6.5 SU) (Figure 35).

Figure 34. Burlington WYPDES Discharge Permit WY0036196 – Daily Maximum pH



Source: Wyoming DEQ 2013d; Wyoming DEQ 2017

Figure 35. Burlington WYPDES Permit WY0036196 – Daily Minimum pH

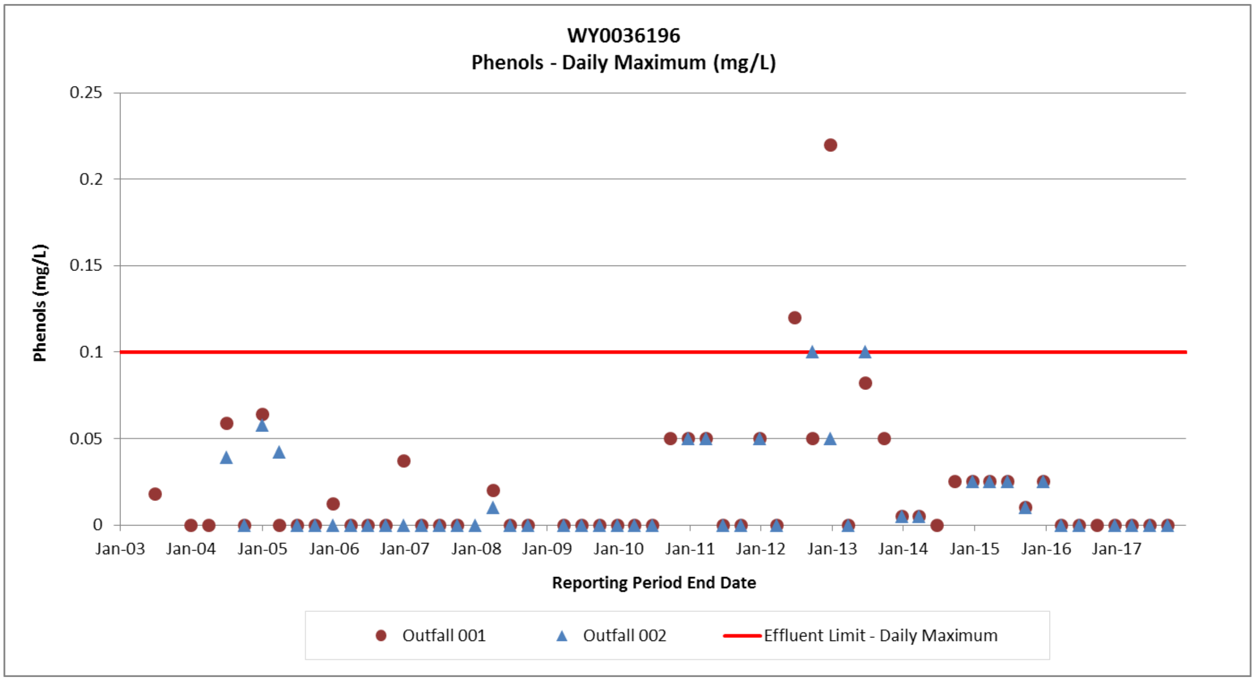


Source: Wyoming DEQ 2013d,; Wyoming DEQ 2017

The daily maximum permit limit for phenols (0.1 mg/L) was equaled or exceeded on four occasions between 2002 and 2017 (Figure 36):

- Outfall 001 2012 (0.12, 0.22 mg/L)
- Outfall 002 2012 (0.1 mg/L)
  2013 (0.1 mg/L)

Figure 36. Burlington WYPDES Permit WY0036196 – Daily Maximum Phenols

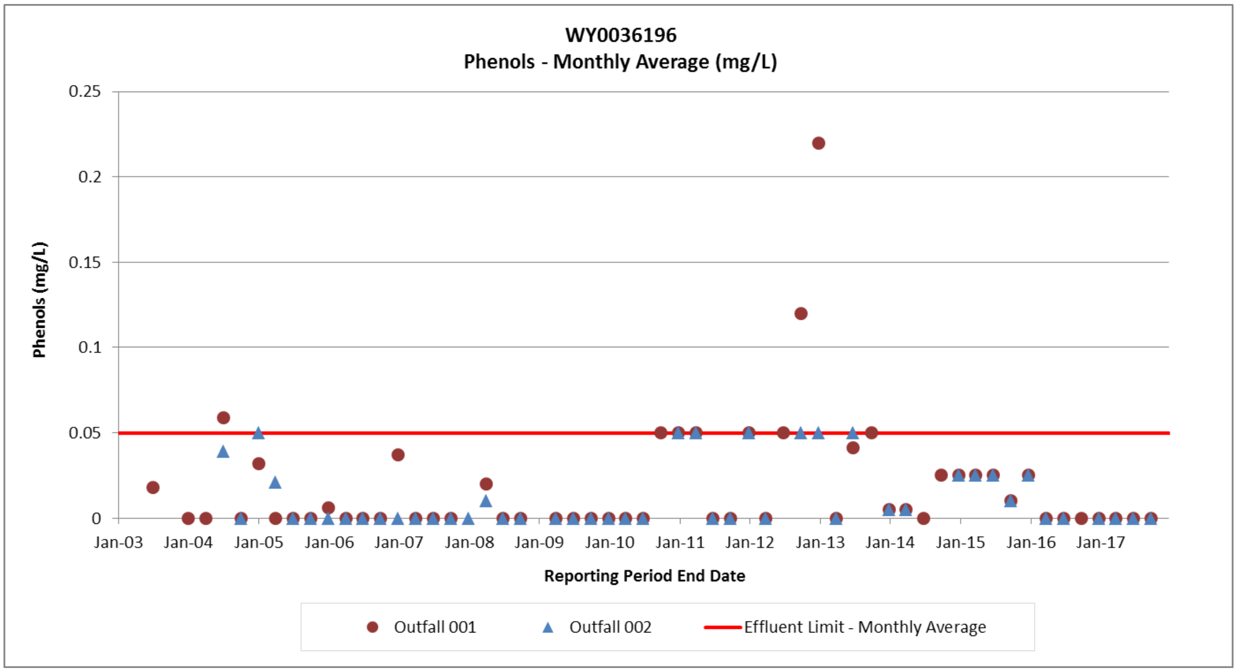


Source: Wyoming DEQ 2013d; Wyoming DEQ 2017
Non-detect values graphed as zero.

The monthly average permit limit for phenols (0.05 mg/L) was equaled or exceeded on several occasions between 2002 and 2017 (Figure 37):

- Outfall 001 2004 (0.059 mg/L)
  2010 (0.05, 0.05 mg/L)
  2011 (0.05, 0.05 mg/L)
  2012 (0.05, 0.12, 0.22 mg/L)
  2013 (0.05 mg/L)
- Outfall 002 2004 (0.05 mg/L)
  2010 (0.05 mg/L)
  2011 (0.05, 0.05 mg/L)
  2012 (0.05, 0.05 mg/L)
  2013 (0.05 mg/L)

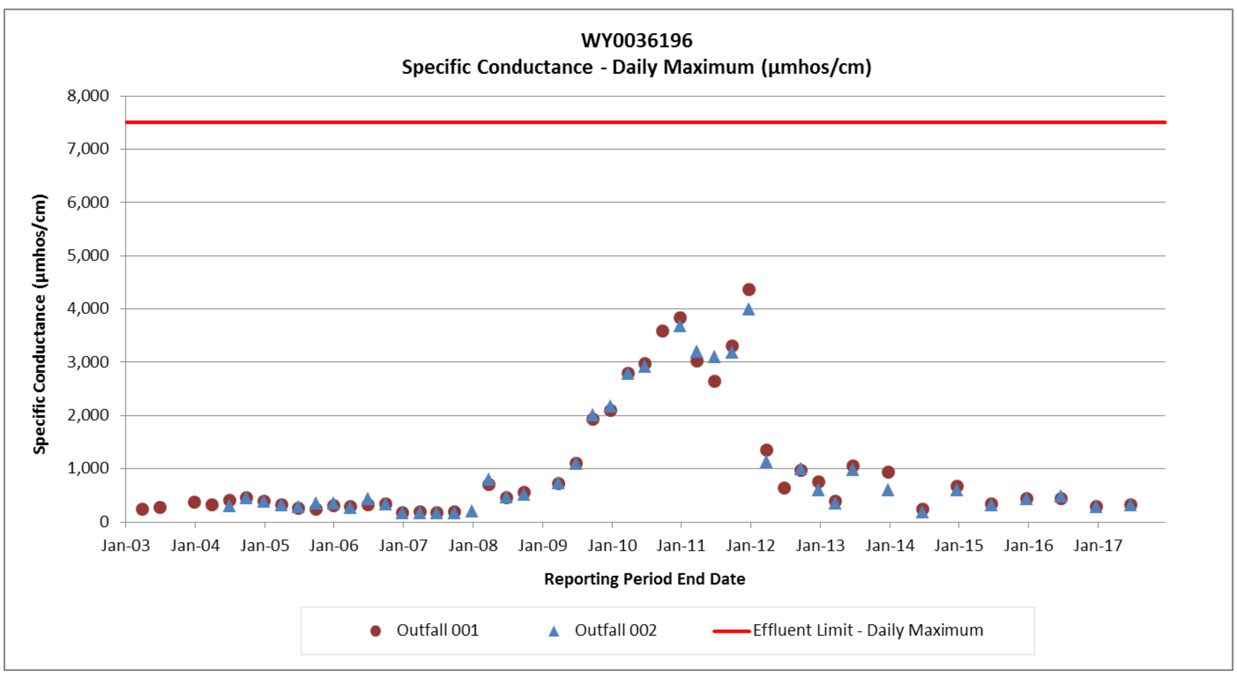
Figure 37. Burlington WYPDES Permit WY0036196 – Monthly Average Phenols



Source: Wyoming DEQ 2013d; Wyoming DEQ 2017
Non-detect values graphed as zero.

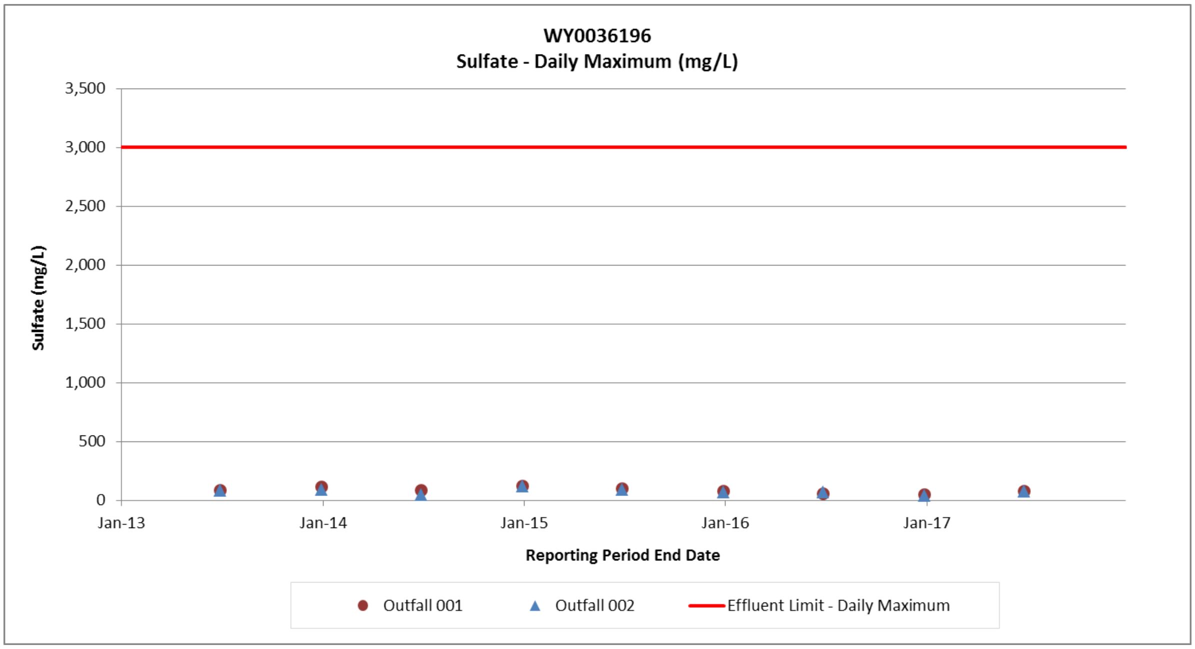
There were no permit limit exceedances during the period of record for specific conductance (7,500 µmhos/cm) (Figure 38) or sulfate (3,000 mg/L) (Figure 39).

Figure 38. Burlington WYPDES Permit WY0036196 – Daily Maximum Specific Conductance



Source: Wyoming DEQ 2013d; Wyoming DEQ 2017

Figure 39. Burlington WYPDES Permit WY0036196 – Daily Maximum Sulfate

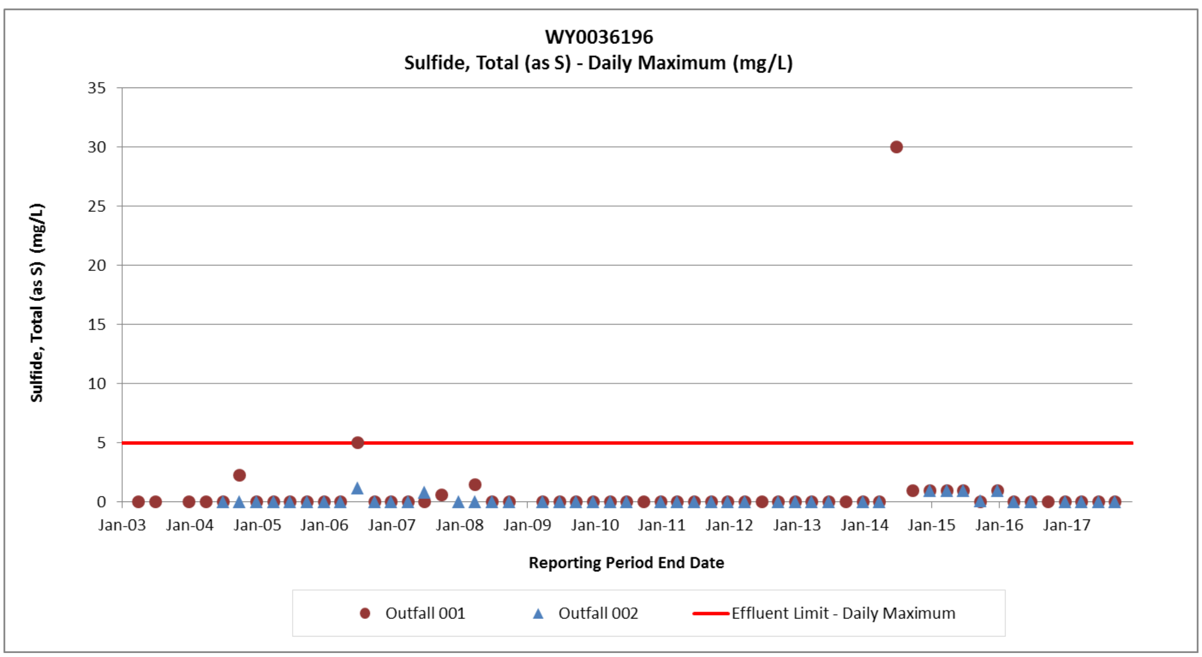


Source: Wyoming DEQ 2013d; Wyoming DEQ 2017

The daily maximum permit limit for total sulfide (5 mg/L) was equaled or exceeded on two occasions between 2003 and 2017 (Figure 40):

- Outfall 001 2006 (5 mg/L)
  2014 (30mg/L)

Figure 40. Burlington WYPDES Permit WY0036196 – Daily Maximum Total Sulfide



Source: Wyoming DEQ 2013d; Wyoming DEQ 2017
Non-detect values graphed as zero.

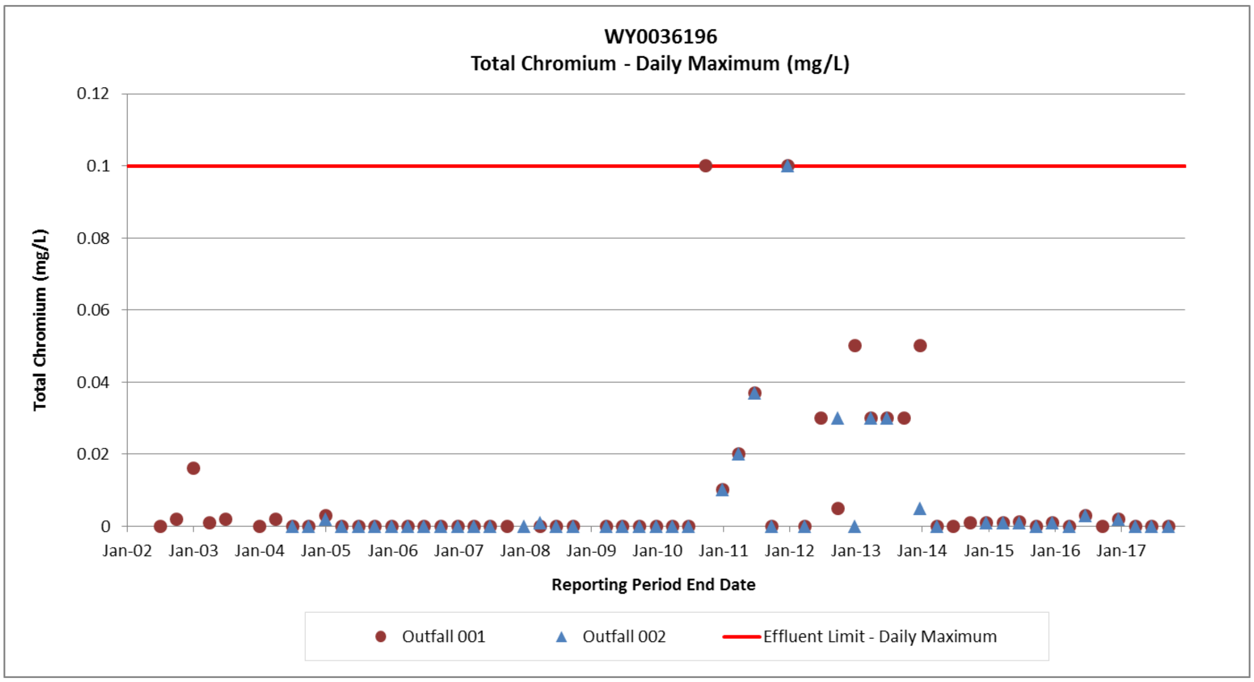
The daily maximum permit limit for total chromium (0.1 mg/L) was equaled on three occasions between 2002 and 2017 (Figure 41):

- Outfall 001 2010 (0.1 mg/L)
  2011 (0.1 mg/L)
- Outfall 002 2011 (0.1 mg/L)

The monthly average permit limit for total chromium (0.05 mg/L) was equaled or exceeded on five occasions between 2002 and 2017 (Figure 42):

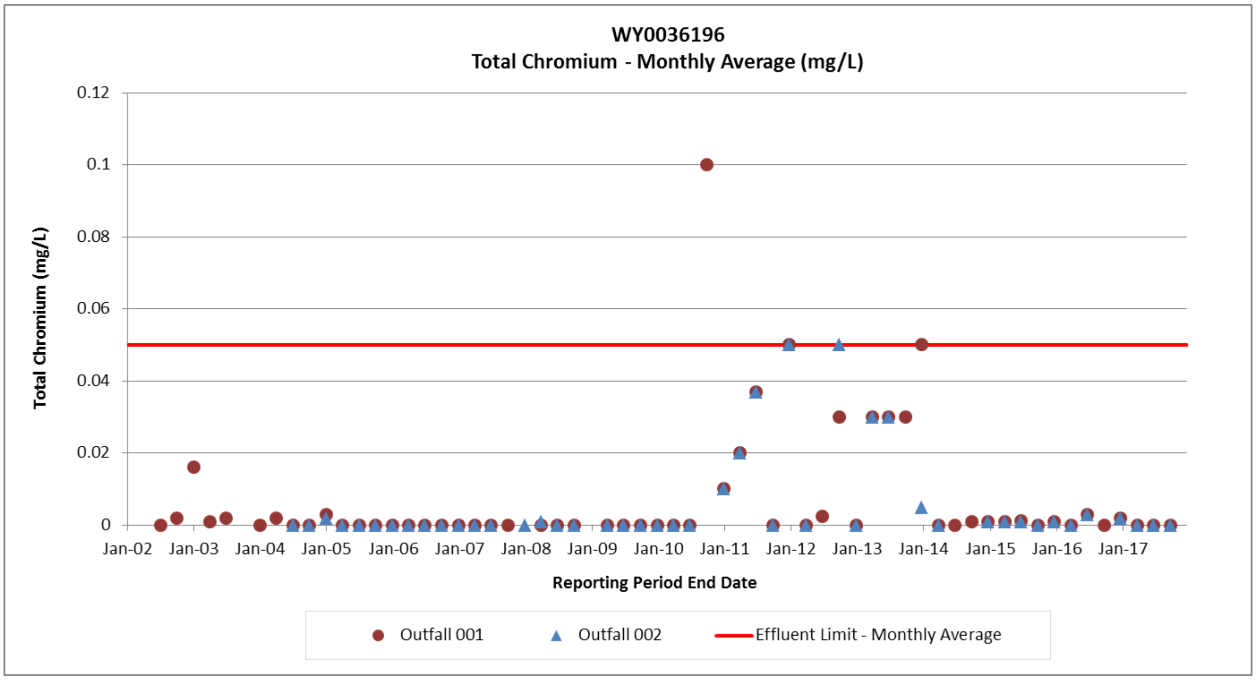
- Outfall 001 2010 (0.1 mg/L)
  2011 (0.05 mg/L)
  2013 (0.05 mg/L)
- Outfall 002 2011 (0.05 mg/L)
  2012 (0.05 mg/L)

Figure 41. Burlington WYPDES Permit WY0036196 – Daily Maximum Total Chromium



Source: Wyoming DEQ 2013d; Wyoming DEQ 2017
Non-detect values graphed as zero.

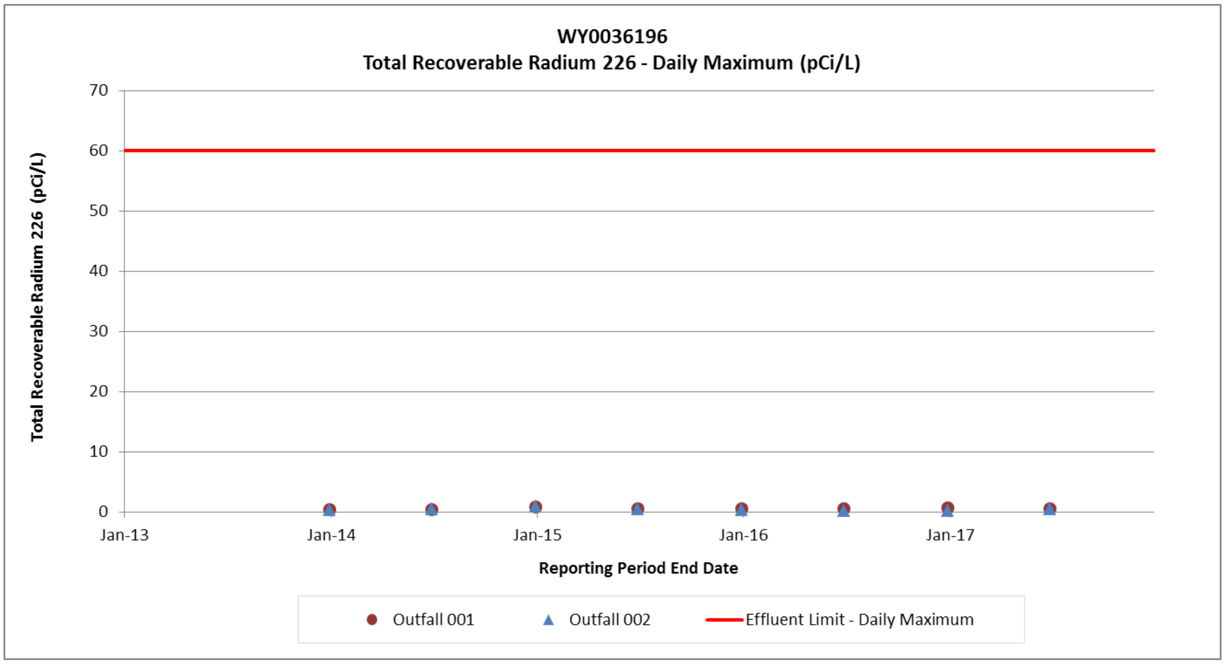
Figure 42. Burlington WYPDES Permit WY0036196 – Monthly Average Total Chromium



Source: Wyoming DEQ 2013d; Wyoming DEQ 2017
Non-detect values graphed as zero.

There were no permit limit (60 picocuries per liter [pCi/L]) exceedances during the period of record for total recoverable radium 226 (Figure 43).

Figure 43. Burlington WYPDES Permit WY0036196 – Daily Maximum Total Recoverable Radium 226



Source: Wyoming DEQ 2013d; Wyoming DEQ 2017

5.6 Retention and Evaporation Ponds

Three water retention/evaporation ponds exist in Aethon's leasehold in the Production Area (Encana 2013). Two ponds have a capacity of 400,000 barrels (bbl) and one pond has a capacity of 800,000 bbl. The ponds are lined and equipped with leak detection systems to prevent accidental releases. The ponds are located on state lands and regulated by Wyoming DEQ. BLM Onshore Order 7 (43 CFR 3160) requires that a Sundry Notice and a copy of the state permit be submitted for the disposal of water from federal leases, even if the disposal occurs on state lands.

6.0 WATER RIGHTS

6.1 Surface Water Rights

There are 826 surface water rights in the analysis area (WSEO 2013). The majority of those water rights are for small (capacity less than 50 acre-feet) stock ponds located in streambeds. Many water rights also exist for diversions from streams into irrigation ditches. The earliest water right was granted in 1884 for the Okie Ditch, which diverts water from Badwater Creek. More than 200 surface water rights exist directly inside the Production Area, more than 60 of which are administered by the Bureau of Land Management (BLM) and one of which is administered by the State of Wyoming. Three surface water rights exist in the center of the proposed Madison Disposal Area. A summary of the analysis area surface water rights by primary use category and facility type is presented in Table 36. The surface water right locations are shown on Figure 44. Refer to Attachment F for a complete list of surface water rights in the analysis area.

Several water rights exist for Boysen Reservoir and the Bighorn River, predating the reservoir (Table 37). The main water right for Boysen Reservoir is held by USBR (P5576.0R) and is allocated to other users through temporary permits (WSEO 2013).

Table 36. Surface Water Rights in the Analysis Area by Primary Use Category and Facility Type

Primary Use Category	**Count**
Stock	374
Irrigation	280
Domestic/Irrigation/Stock	127
Reservoir Supply	18
Industrial/Miscellaneous	10
Flood Control/Stock	8
Railroad	5
Fish Propagation	2
Instream Flow	1
Recreation	1
Total	**826**
Facility Type	***Count***
Reservoir	417
Stream	316
Spring	92
In Stream	1
Total	**826**

Source: WSEO 2013

Table 37. Boysen Reservoir Water Rights

Water Right Number	Priority Date	Name/Company	Facility Name	Total Flow (cfs)	Stream Source	Size of Reservoir (acre-feet)
P8628.0D	09/08/1908	Warren	Warren Ditch	1.39	Wind River	0
P35179.0D	04/02/2014	Marathon Petroleum Company	Brickner-Wind River Hdd Water Haul	0.9	Bighorn River	0
P3947.0E	10/16/1918	Anderson August	Bell The Cat Ditch, The 2nd Enlargement	0.56	--	0
CR CC39/400	08/02/1910	Sidenbender	Bell The Cat Ditch	1.94	Bighorn River	0
P9010.0D (CR CC38/651)	04/15/1909	Town of Shoshoni	Shoshoni Pipe Line	0.66	Bighorn River	0
P35215.0D	05/27/2014	Fremont County Transportation Dept.	Boysen Reservoir Water Haul	0.29	Bighorn River	0
P35213.0D	05/23/2014	Marathon Petroleum Company	Brickner-Wind River Water Haul	0.9	Bighorn River	0
P1256.0R	11/01/1901	Wyoming Power Co.	Asmus Boysen Reservoir	--	Bighorn River	60035
P11541.0D (CR CC42/312)	05/24/1912	Chicago Burlington Quincy Railroad Company	Boysen Pipe Line	0.69	Bighorn River	0
P29614.0D	10/21/1986	Wyo. State Parks & Historic Sites	Boysen Water System	0.12	Bighorn River	0
P5576.0R (CR CR06/077)	10/22/1945	USDI Bureau Of Reclamation	Boysen Reservoir	--	Bighorn River	757851
P22872.0D	04/08/1964	USDI - BLM	Boysen Powerplant Pipeline	2600	Bighorn River	0
P3770.0E (CR CC41/712)	03/20/1917	Anderson	Jente Ditch, Enlargement	0.17	--	0

Source: WSEO 2013
cfs = cubic feet per second

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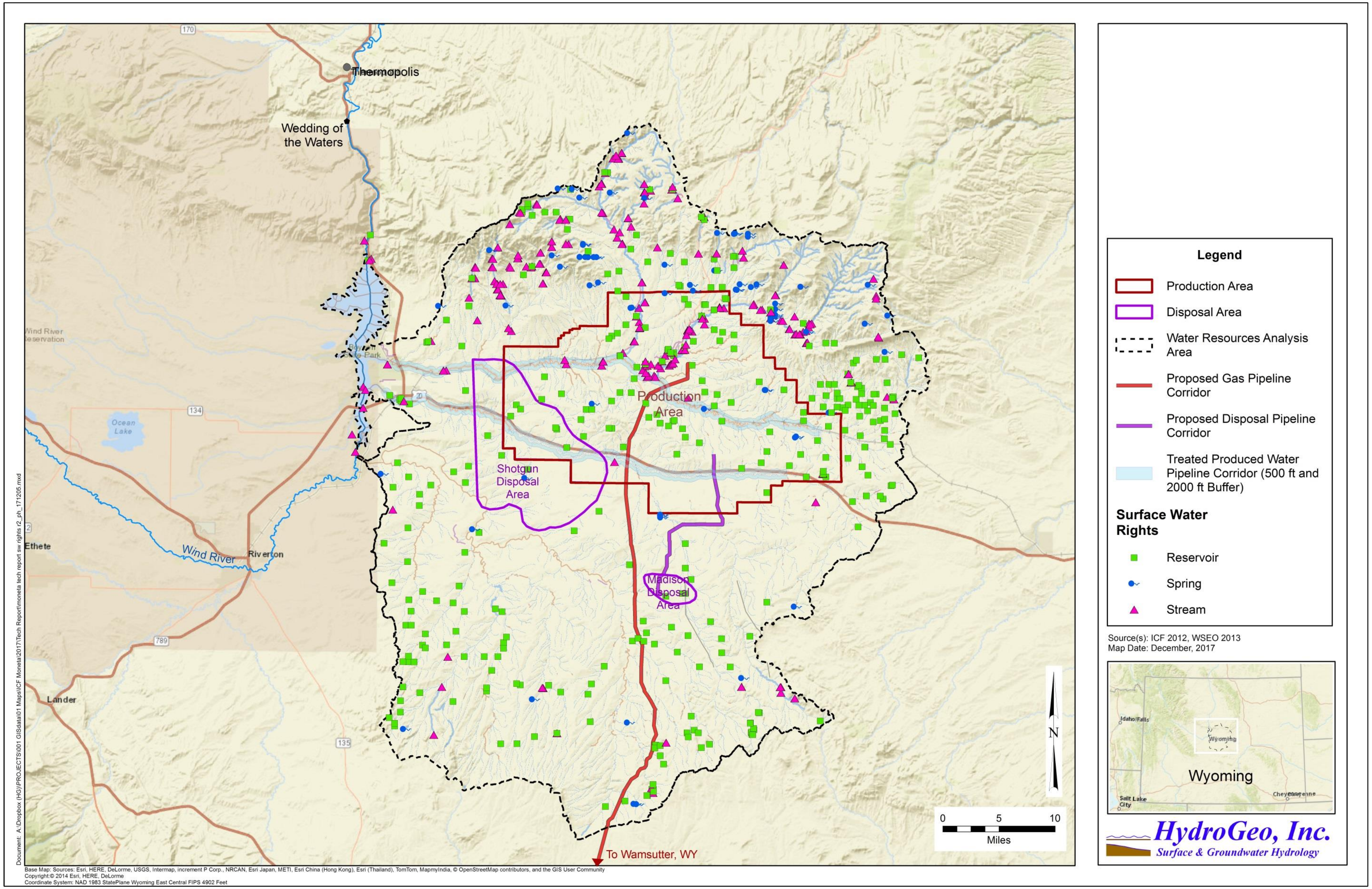
Figure 44. Surface Water Rights Map



Source: ICF 2012; WSEO 2013

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6.2 Groundwater Rights

The analysis area has 995 groundwater rights for wells (WSEO 2013). The majority of the wells are used for stock watering, monitoring, domestic, and industrial purposes, while a few are used for government and irrigation purposes. All water wells in the Production Area are completed in the Wind River aquifer or in overlying unconsolidated deposits (Section 5.1.1, *Wind River and Quaternary Unconsolidated Deposit Aquifers*). In the analysis area, the average water well depth is 299 feet. The groundwater rights in the analysis area are summarized in Table 38 and their locations are shown on Figure 45. Refer to Attachment G for a complete list of groundwater rights in the analysis area.

Table 38. Groundwater Rights in the Analysis Area

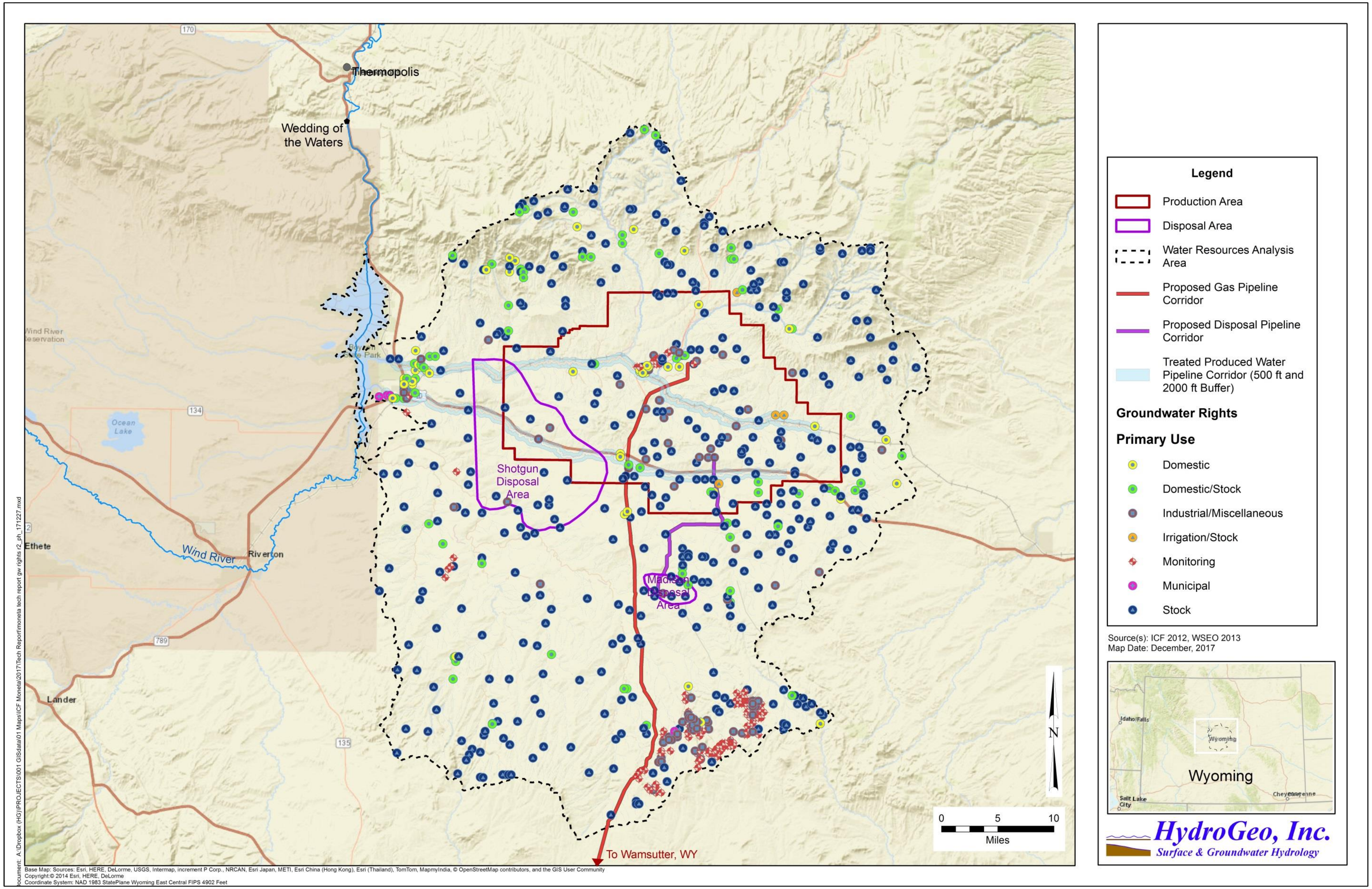
Primary Use Category	Domestic	Domestic/ Stock	Irrigation/ Stock	Stock	Industrial/Mis c.	Monitoring	Municipal	All
Number of Groundwater Rights in Analysis Area	84	89	4	426	115	270	7	**995**
Number of Well Records with Depth Reported in Analysis Area	79	88	2	388	94	246	7	**904**
Minimum Total Depth (feet) of Wells in Analysis Area	0	0	170	0	53	11	110	**0**
Maximum Total Depth (feet) of Wells in Analysis Area	1,000	3,000	180	4,932	24,877	827	1,051	**24,877**
Average Total Depth (feet) of Wells in Analysis Area	248	249	175	198	1,038	205	498	**299**
Number of Well Records in Production Area[1]	31	0	3	88	24[2]	47	0	**193**
Number of Well Records with Depth Reported in Production Area	30	0	1	77	15	47	2	**172**
Minimum Total Depth (feet) of Wells in Production Area	20	0	180	40	250	13	240	**13**
Maximum Total Depth (feet) of Wells in Production Area	450	0	180	1360	1040	100	270	**1360**
Average Total Depth (feet) of Wells in Production Area	203	0	180	328	696	34	255	**256**

Source: WSEO 2013

[1] All water wells in the Production Area are completed in Quaternary unconsolidated deposit aquifers or in the Wind River aquifer

[2] Misc. wells include the Freemont County School District Well and BLM Webb Ranch Unit 2-19 Water Well

Figure 45. Groundwater Rights Map



Source: ICF 2012; WSEO 2013

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7.0 REFERENCES

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ATTACHMENTS

The following attachments to the Water Resources Technical Report for the Moneta Divide Natural Gas and Oil Development Project are on file at the BLM Lander Field Office, 1335 Main Street, Lander, WY 82520, phone: 307-332-8400, and are available upon request. The attachments are also available for download on the Moneta Divide Project EIS website: https://go.usa.gov/xQr83.

Attachment A	USBR Boysen Reservoir Data
Attachment B	Wyoming DEQ Water Quality Rules and Regulations Chapter 1
Attachment C	Surface Water Quality Data
Attachment D	WOGCC Produced Water Quality Data
Attachment E	WYPDES Discharge Monitoring Report Data
Attachment F	Surface Water Rights
Attachment G	Groundwater Rights