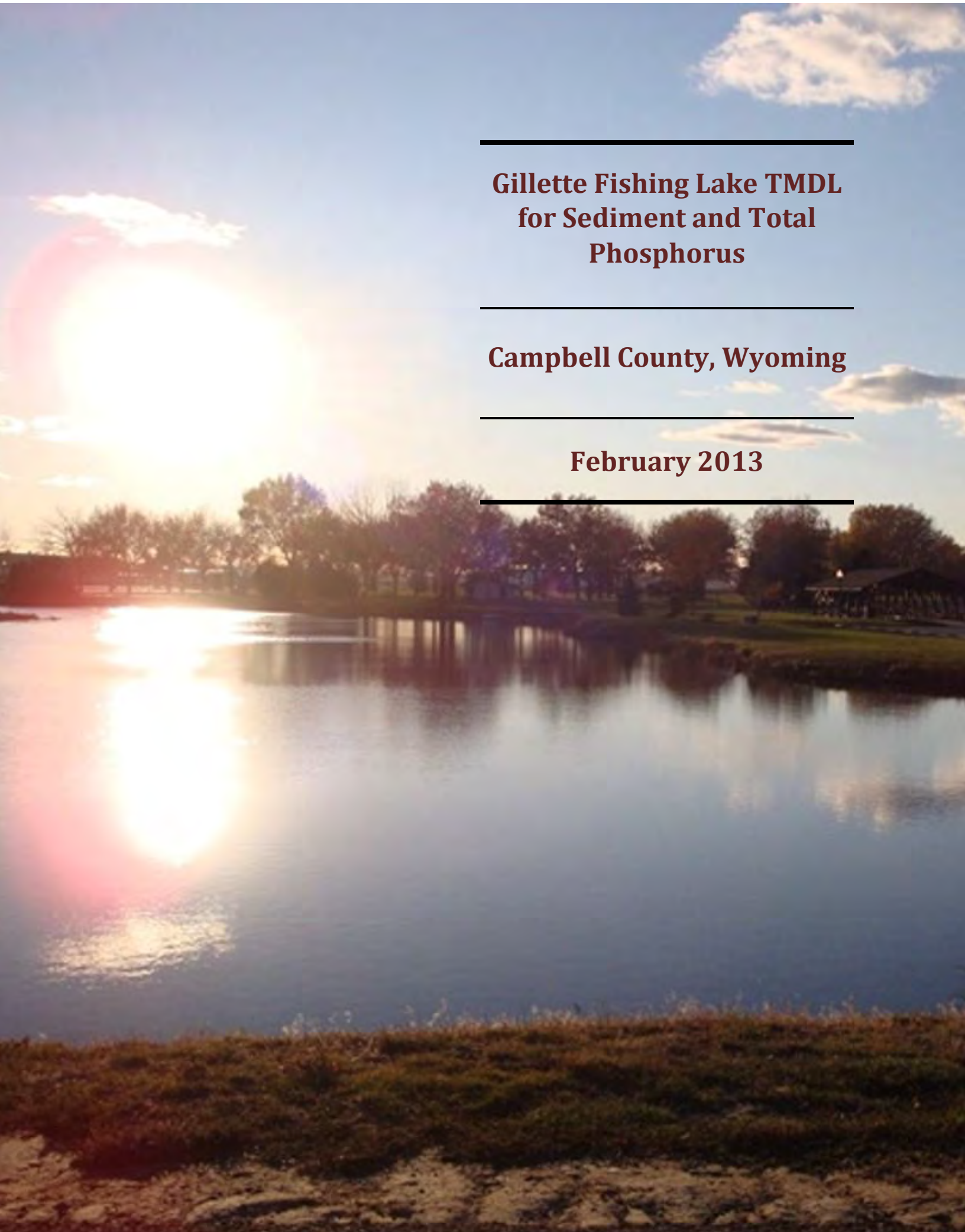

Gillette Fishing Lake TMDL for Sediment and Total Phosphorus

Campbell County, Wyoming

February 2013

WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY
WATER QUALITY DIVISION AND THE CITY OF GILLETTE

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February 26, 2013

TMDL Quick Summary

Waterbody Name	Gillette Fishing Lake
303(d) Waterbody ID	WYBF101202010601_01
Waterbody Classification	Class 2ABww
Location	Campbell County, Wyoming
Pollutant(s) of Concern	Sediment and Phosphate
Impaired Designated Uses	Warm Water Fisheries and Aquatic Life other than Fish
Number of TMDLs	2
Targets	Sediment – 252 tons per year of accumulated sediment within the lake Total Phosphorus – 50 µg/L (45 µg/L with MOS) or 160 pounds per year of Total Phosphorus
Existing Conditions	41,540 cubic yards of accumulated sediment within the lake 177 µg/L average growing season Total Phosphorus
Existing Load	1,120 tons per year of accumulated sediment within the lake 1,258 tons per year of sediment within the lake plus transmission of sediment downstream 920 pounds per year of Total Phosphorus loading
Target Annual Load/Daily Load	252 tons per year/ 0.69 tons per day of accumulated sediment within the lake 160 pounds per year / 0.43 pounds per day of Total Phosphorus
Annual / Daily Wasteload Allocation (WLA)	0 tons per year / 0 tons per day of accumulated sediment 0 pounds per year / 0 pounds per day of Total Phosphorus loading
Annual / Daily Load Allocation (LA)	252 tons per year / 0.69 tons per day of accumulated sediment within the lake 160 pounds per year / 0.43 pounds per day of Total Phosphorus
Margin of Safety (MOS)	Explicit 10% reduction of TP Target Implicit for sediment

EXECUTIVE SUMMARY

The Federal Clean Water Act requires the Wyoming Department of Environmental Quality—Water Quality Division (WDEQ/WQD) to develop a Total Maximum Daily Load (TMDL) for pollutant(s) in waters that have been identified on the State of Wyoming's (the State's) §303(d) list as impaired. Gillette Fishing Lake is impaired due to excess sediment and phosphate (a naturally occurring form of the phosphorus element). It has been on the §303(d) list since 1996. Original 1996 designated uses affected by sediment and phosphate are Cold Water Fisheries and Aquatic Life other than Fish. The purpose of the TMDL for Gillette Fishing Lake is to calculate the target sediment and total phosphorus (TP) loads for the lake in order to meet water quality standards and provide Gillette Fishing Lake with the water quality needed to support its designated uses.

The source of sediment and phosphorus is from nonpoint sources in the Gillette Fishing Lake watershed. As noted in the Fishing Lake Water Quality Study (205j report), the subbasins directly adjacent to Gillette Fishing Lake contribute stormwater runoff, which carry the sediment and phosphorus contributing to the excess loading (ICD, 1995). This project uses subbasin delineation of the Gillette Fishing Lake watershed to analyze the current and allowable load of sediment and phosphorus. The TMDL results, as well as the 205j report, notes these adjacent subbasins are the primary sources of the pollutants carried by stormwater runoff, a nonpoint source (ICD, 1995). Internal loading from the accumulated sediment also contributes to the current load within Gillette Fishing Lake.

The water quality goal of this TMDL is to reduce sediment and phosphorus loading to acceptable levels consistent with the water quality standards for Gillette Fishing Lake. A Use Attainability Assessment (UAA) completed in 2011, changed the designation from a 2AB Cold Water fishery (2AB) to 2AB Warm Water Fishery (2ABww). Therefore, the reductions developed should reduce sedimentation and eutrophic and hypereutrophic state of the lake. This will allow Gillette Fishing Lake to support successful warm water fisheries and aquatic life other than fish uses. The TMDL for sediment derives from the TP target, specifically the particulate phosphorus. The TMDL target for TP was determined by conducting a thorough literature review, data analysis and a weight of evidence approach.

The target sediment load to Gillette Fishing Lake is 252 tons per year or 0.69 tons per day of accumulated sediment and this report allocates the entire load to the nonpoint sources. Analysis concludes that point sources are not contributors of sediment. The margin of safety (MOS) for the sediment load is implicitly applied from the MOS of the TP target calculation. Sediment reductions of 78 percent will ensure attainment of water quality standards.

The target TP load is 160 pounds per year or 0.44 pounds per day and is determined using a 45µg/L concentration of TP. This report allocates the entire load to the nonpoint sources. Analysis concludes that point sources are not contributors of phosphorus. The MOS for the phosphorus TMDL is an explicit 10 percent. The analysis determines that TP needs an 83 percent reduction of the current load to meet water quality standards.

This report establishes secondary targets in addition to the sediment and TP targets. Secondary target ranges allow for additional data collection and analysis to determine if TP and sediment

targets are trending towards reductions. These secondary targets are chlorophyll a and secchi disk depths with ranges of 10 to 25 µg/L and 0.70 to 0.81 meters respectively.

This report recommends monitoring to substantiate baseline conditions and to determine the effectiveness of the targets established. Monitoring includes continuing sampling for TP at the three lake sampling locations, TP sampling at the inlet and outlet of the lake, monthly flow measurements, conduct a sediment survey every 5 years and continue to monitor fish populations.

Thorough public participation occurred during this project and included public meetings, stakeholder conference calls and a public comment period for the report. The one comment received during the comment period approved of the project and did not require any response.

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LIST OF ACRONYMS

BMP	best management practice
CBM	coal bed methane
CCCD	Campbell County Conservation District
CIP	Capital Improvement Plan
CFR	Code of Federal Regulations
CWA	Clean Water Act
DO	dissolved oxygen
LA	load allocation
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MOS	margin of safety
NHD	National Hydrography Dataset
NRCS	Natural Resources Conservation Service
RUSLE	Revised Universal Soil Loss Equation
SDR	sediment delivery ratio
TMDL	Total Maximum Daily Load
TP	total phosphorus
TSI	Trophic State Index
UAA	Use Attainability Assessment
µg/L	micrograms per liter
USBR	United State Bureau of Reclamation
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
USLE	Universal Soil Loss Equation
WDEQ	Wyoming Department of Environmental Quality

WDEQ/WQD	Wyoming Department of Environmental Quality—Water Quality Division
WGFD	Wyoming Game and Fish Department
WLA	Wasteload Allocation
WYPDES	Wyoming Pollutant Discharge Elimination System

1.0 INTRODUCTION

The federal Clean Water Act (CWA) §303(d) and 40 Code of Federal Regulations (CFR) 130.7 direct each state to develop a Total Maximum Daily Load (TMDL) for all waters that have been identified on their respective 303(d) lists as impaired by pollutant(s). A TMDL incorporates elements that address the statutory and regulatory requirements of the CWA, along with the documentation that serves as the basis for the TMDL. These elements include an assessment of the pollutant problem and impacts on designated uses, development of numeric targets that interpret and apply the water quality standard(s), an assessment of the pollutant sources, an estimation of loading capacity, associated load allocations and a margin of safety (MOS).

TMDL = WLA (wasteload allocation/regulated point sources) + LA (load allocation/ nonpoint sources) + MOS (margin of safety)

Wyoming's 1996 §303(d) list initially identifies Gillette Fishing Lake as water quality limited due excessive sediment and high concentrations of phosphate (a naturally occurring form of the phosphorus element). The level of sediment and phosphate in Gillette Fishing Lake was determined to threaten the existing water quality standards supportive of cold water fisheries and aquatic life other than fish. Although the designated use of Gillette Fishing Lake has changed from cold water to warm water fisheries, the lake still failed to meet the water quality standards for sediment and phosphate.

The CWA requires the Wyoming Department of Environmental Quality/Water Quality Division (WDEQ/WQD) to develop a TMDL for Gillette Fishing Lake. According to Wyoming's TMDL Workplan (WDEQ/WQD, 2008), this TMDL will be reassessed at least every 5 years. Reassessments are an iterative approach to refining the TMDL as new information becomes available or environmental conditions in the watershed change significantly over time. This approach also allows WDEQ/WQD to use a feedback loop to determine if the initial sediment and TP targets are effective in reaching the ultimate goal of having Gillette Fishing Lake meet water quality standards and fully supporting the designated uses. Revisions to the water quality standards may warrant the recalculation of these TMDLs. If WDEQ/WQD proposes changes to the Gillette Fishing Lake TMDL after future reassessment, a new public comment period and review by the U.S. Environmental Protection Agency (USEPA) will occur.

This TMDL consists of estimating the pollutant load capacity of Gillette Fishing Lake, the existing pollutant load in excess of this capacity, and source load allocations based on available information. Included with this TMDL is a recommended monitoring plan, which is necessary to assess the future designated use status, determines water quality trends, and evaluates the effectiveness of implemented best management practices (BMP). An implementation plan is also included to bring Gillette Fishing Lake back into compliance with its designated uses and associated water quality standards.

2.0 WATERSHED AND WATERBODY DESCRIPTION

Gillette Fishing Lake is a manmade reservoir located in the southeastern section of the City of Gillette (the City) in Campbell County, Wyoming (Figure 1). Fishing Lake Dam constructed on Donkey Creek established Gillette Fishing Lake in 1949. Gillette Fishing Lake currently has a mean depth of approximately 5.3 feet, a maximum depth of 10.4 feet and a storage volume of approximately 92 acre-feet. Total surface area of the lake is approximately 25 acres. Lake acreage is determined from information in the original engineering design plans and through analysis of current contour lines and aerial photos (City of Gillette, 2010). In addition to these area estimation methods, the Fishing Lake Water Quality Study estimates the lake at 25 acres (ICD, 1995). Ice-cover is typically present on Gillette Fishing Lake from the end of November to the middle of April.

Total contributing watershed area is 25,717 acres. Therefore, the watershed-to-lake ratio is approximately 1,000: 1. Dalbey Park contains Gillette Fishing Lake and is an important fishing location for local residents. Gillette Fishing Lake is the closest fishery for the public, followed by Keyhole Reservoir, which is located more than 30 miles east of the City.

Land uses within the Gillette Fishing Lake watershed are in Table 1 (University of Wyoming, Spatial Data and Visualization Center, 2009). Land uses within a watershed can affect the water quality of a waterbody. Therefore, the land uses for the Gillette Fishing Lake watershed were an integral part of the watershed loading calculations. Some examples of sediment contributions from the urban areas are roadway sediment and sediment runoff from construction areas. The City is a continuously growing community. Therefore, Table 1 lists the construction and urban land uses separately, and Figure 2 displays construction and urban land uses combined. The rural residential areas can also contribute sediment and phosphorus. The application of lawn fertilizers is an example of a contributing source of phosphorus within a watershed. The agricultural lands within the watershed primarily consist of rangeland. About 87 percent of Campbell County is rangeland. Rangeland consists of upland shrub and Wyoming Big SageBrush cover types with short prairie grass and sagebrush plants as the primary vegetative cover. Shrub lands tend to consist of sagebrush, but greasewood and rabbitbrush may be locally dominant (Campbell County, 2007). Precipitation can create soil erosion and conditions that deliver sediment and phosphorus loads from the rangeland lands.

TABLE 1 – LAND USE FROM GIS

Land Use from GIS	Description of the Land Use	Area(Acres)	Area (%)
Road	Roadways	492	2%
Rural Residential	Single-family housing in the rural development areas	3,454	13%
Urban	Residential, commercial, and industrial area	2,224	9%
Construction	Construction areas within the urban land use category	139	1%
Upland shrub	Western rangeland dominated by shrub species	6,847	27%
Wyoming big sagebrush	Western rangeland dominated by Wyoming Big Sage Brush	12,192	47%
Water	Ponds, drainages, and large wetland complexes	369	1%
Total		25,717	100%
(University of Wyoming, Spatial Data and Visualization Center, 2009),(City of Gillette, 2010)			

Subbasin delineation of Gillette Fishing Lake watershed is accomplished using contour information provided by the City of Gillette (City of Gillette, 2008). Table 2 and Figure 2 list and display the land uses within the direct watershed and the subbasins. Original landuse data came from the University of Wyoming, Spatial Data and Visualization Center (2009).The City of Gillette and the Campbell County Conservation District updated the land use data in 2010 by using aerial imagery and a 2010 City of Gillette Roads coverage (City of Gillette, 2010).

FIGURE 1 – GILLETTE FISHING LAKE WATERSHED

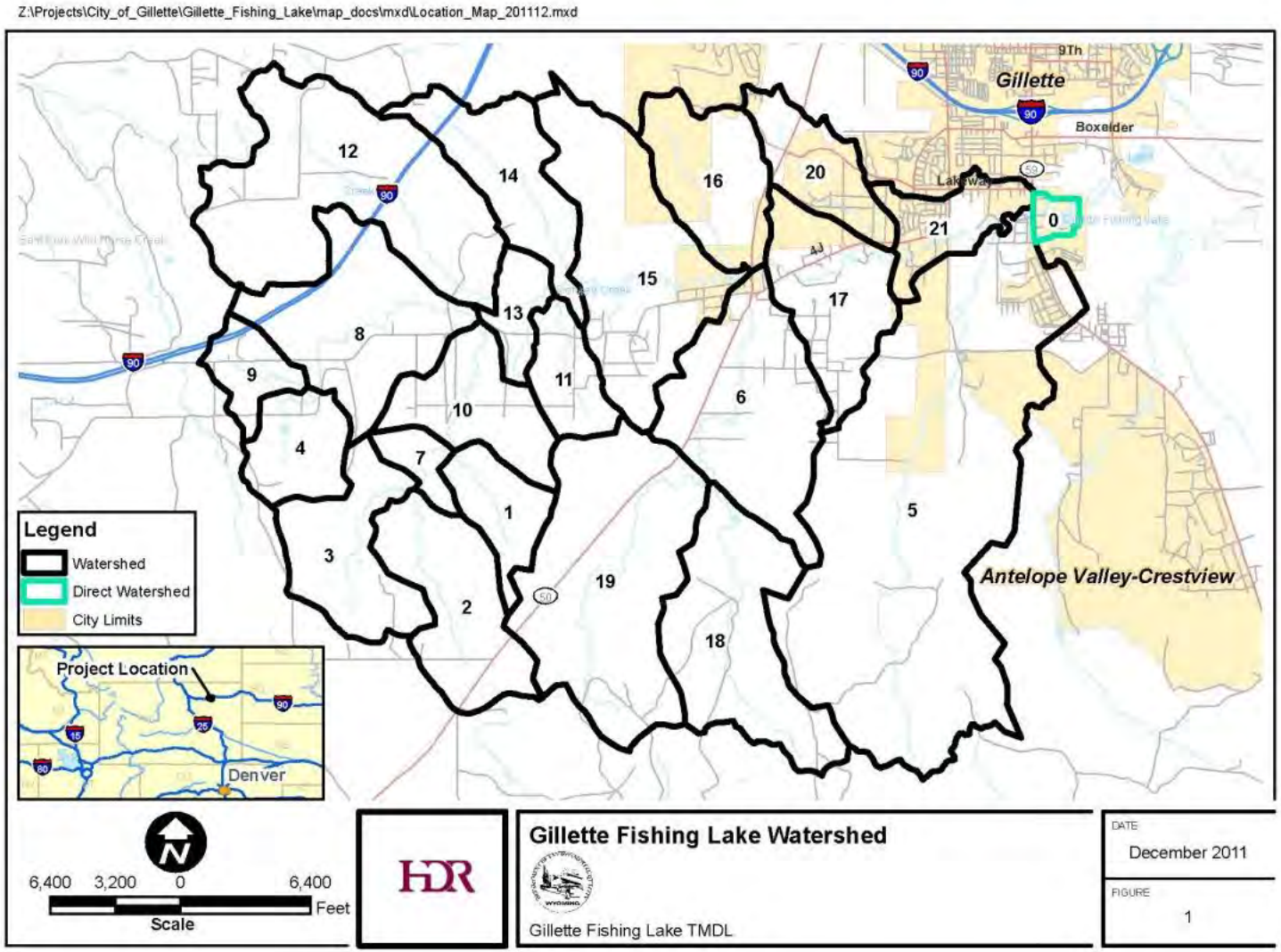
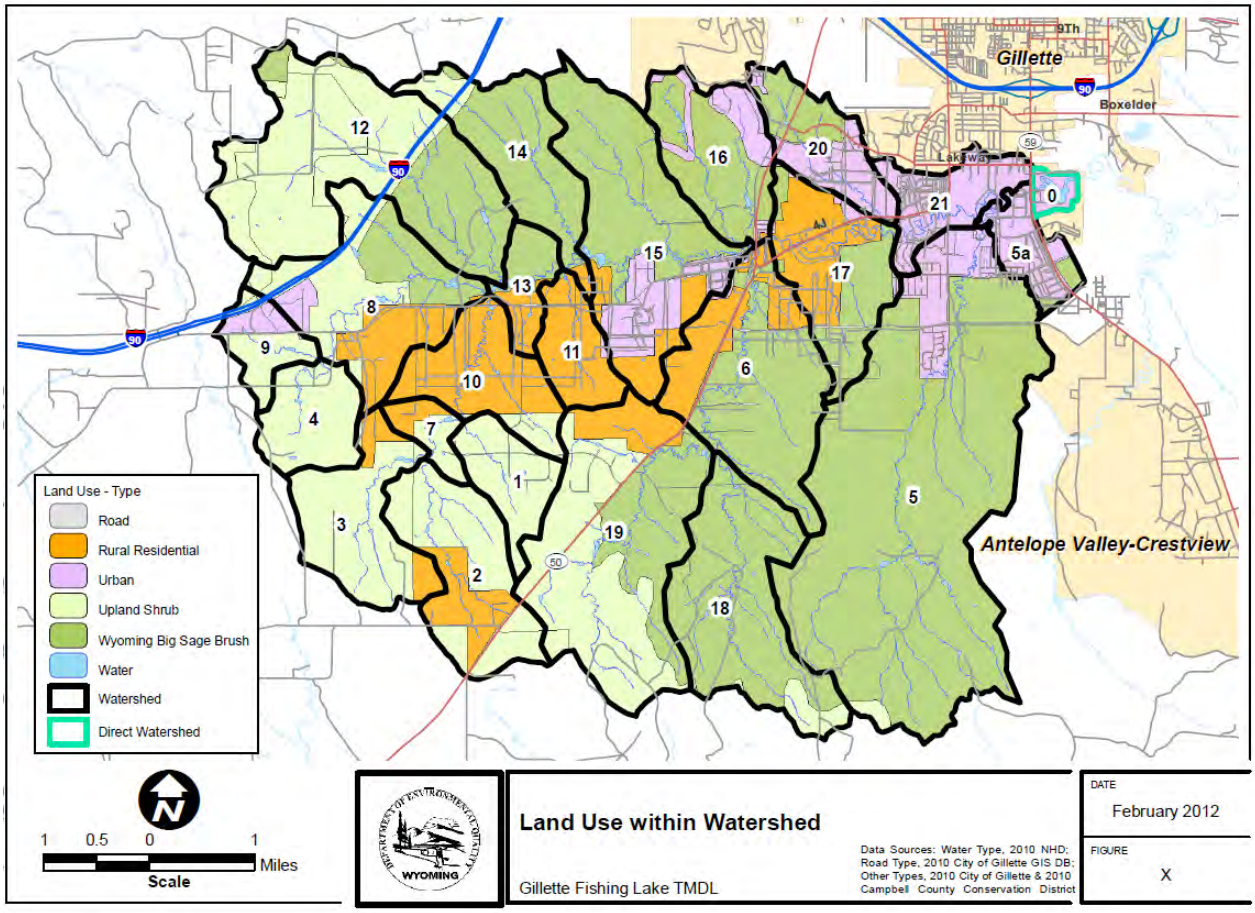


TABLE 2 – LAND USE BY SUBBASIN

Land Use	Construction		Road		Rural Residential		Upland Shrub		Urban		Water		Wyoming Big Sage Brush		
Subbasins	**Area (Acres)**	**Area**	**Area (Acres)**	**Area**	**Area (Acres)**	**Area**	**Area (Acres)**	**Area**	**Area (Acres)**	**Area**	**Area (Acres)**	**Area**	**Area (Acres)**	**Area**	**Total Sum of Area (Acres)**
Direct Watershed	0.21	0.21%	2.04	2.1%	0.00	0.0%	0.00	0.0%	79.09	79.6%	18.07	18.2%	0.00	0.0%	99.41
Subbasin 1	0.00	0.00%	10.16	2.1%	0.33	0.1%	476.50	97.0%	0.00	0.0%	4.05	0.8%	0.00	0.0%	491.05
Subbasin 2	0.00	0.00%	9.34	0.9%	285.86	26.1%	789.35	71.9%	0.00	0.0%	12.75	1.2%	0.00	0.0%	1097.30
Subbasin 3	0.00	0.00%	4.61	0.5%	144.14	15.1%	796.24	83.3%	0.00	0.0%	11.36	1.2%	0.00	0.0%	956.36
Subbasin 4	0.00	0.00%	0.00	0.0%	0.52	0.1%	549.78	98.5%	0.00	0.0%	7.77	1.4%	0.00	0.0%	558.07
Subbasin 5	15.85	0.32%	60.34	1.2%	0.00	0.0%	45.90	0.9%	344.25	7.0%	50.16	1.0%	4427.88	89.6%	4944.39
Subbasin 5a	5.81	1.56%	47.42	12.7%	0.00	0.0%	0.00	0.0%	266.09	71.5%	3.25	0.9%	49.83	13.4%	372.40
Subbasin 6	24.89	1.55%	40.14	2.5%	399.51	24.9%	0.00	0.0%	16.01	1.0%	21.79	1.4%	1103.29	68.7%	1605.64
Subbasin 7	0.00	0.00%	2.19	1.0%	84.81	39.0%	126.41	58.1%	0.00	0.0%	4.18	1.9%	0.00	0.0%	217.59
Subbasin 8	0.00	0.00%	33.06	2.3%	374.46	26.3%	556.57	39.1%	78.65	5.5%	23.99	1.7%	355.16	25.0%	1421.89
Subbasin 9	0.00	0.00%	9.90	2.8%	0.00	0.0%	249.88	71.2%	87.51	24.9%	3.91	1.1%	0.00	0.0%	351.20
Subbasin 10	0.75	0.09%	17.76	2.2%	649.85	81.5%	118.11	14.8%	0.00	0.0%	10.61	1.3%	0.10	0.0%	797.17
Subbasin 11	14.13	3.13%	10.22	2.3%	410.30	91.0%	0.00	0.0%	8.65	1.9%	4.73	1.0%	2.94	0.7%	450.98
Subbasin 12	0.00	0.00%	14.79	0.6%	0.00	0.0%	1603.66	67.3%	0.00	0.0%	28.00	1.2%	737.34	30.9%	2383.79
Subbasin 13	0.01	0.00%	4.33	1.4%	126.36	39.6%	0.00	0.0%	0.00	0.0%	10.83	3.4%	177.47	55.6%	318.99
Subbasin 14	1.48	0.16%	6.35	0.7%	25.14	2.7%	112.29	12.1%	0.00	0.0%	12.03	1.3%	769.04	83.0%	926.33
Subbasin 15	21.17	1.16%	41.36	2.3%	246.54	13.6%	0.00	0.0%	339.89	18.7%	28.09	1.5%	1141.38	62.8%	1818.43
Subbasin 16	19.85	2.19%	17.36	1.9%	5.00	0.6%	0.00	0.0%	208.67	23.0%	15.52	1.7%	641.51	70.7%	907.91
Subbasin 17	6.39	0.64%	33.99	3.4%	460.69	45.9%	0.00	0.0%	41.73	4.2%	15.28	1.5%	446.25	44.4%	1004.33
Subbasin 18	0.00	0.00%	10.68	0.7%	0.00	0.0%	127.90	8.4%	0.00	0.0%	24.81	1.6%	1365.99	89.3%	1529.39
Subbasin 19	0.55	0.02%	26.05	1.1%	237.56	10.2%	1294.45	55.6%	0.00	0.0%	37.85	1.6%	730.03	31.4%	2326.49
Subbasin 20	19.29	3.13%	34.75	5.6%	2.65	0.4%	0.00	0.0%	310.91	50.5%	7.25	1.2%	240.76	39.1%	615.62
Subbasin 21	9.06	1.73%	55.23	10.6%	0.00	0.0%	0.00	0.0%	442.42	84.7%	12.68	2.4%	2.82	0.5%	522.20
Grand Total	139.44	15.91%	492.07	60.8%	3453.75	416.9%	6847.04	678.3%	2223.89	372.4%	368.97	50.6%	12191.79	705.1%	25716.95

FIGURE 2 – LAND USE WITHIN THE GILLETTE FISHING LAKE WATERSHED



Gillette Fishing Lake receives inflows from Donkey Creek and localized stormwater. The U.S. Geological Survey (USGS) National Hydrography Dataset (NHD) designates Donkey Creek as a perennial stream, but at times, no-flow conditions occur. Current estimated annual inflows for Donkey Creek are 666 acre-feet per year. Outflow estimates of 728 acre-feet per year leave Gillette Fishing Lake by means of Donkey Creek. The outflow estimate is higher than the inflow estimate because the inflow estimate does not include direct runoff, precipitation on the lake, groundwater infiltration or changes in lake storage. Table 3 summarizes general information for Gillette Fishing Lake.

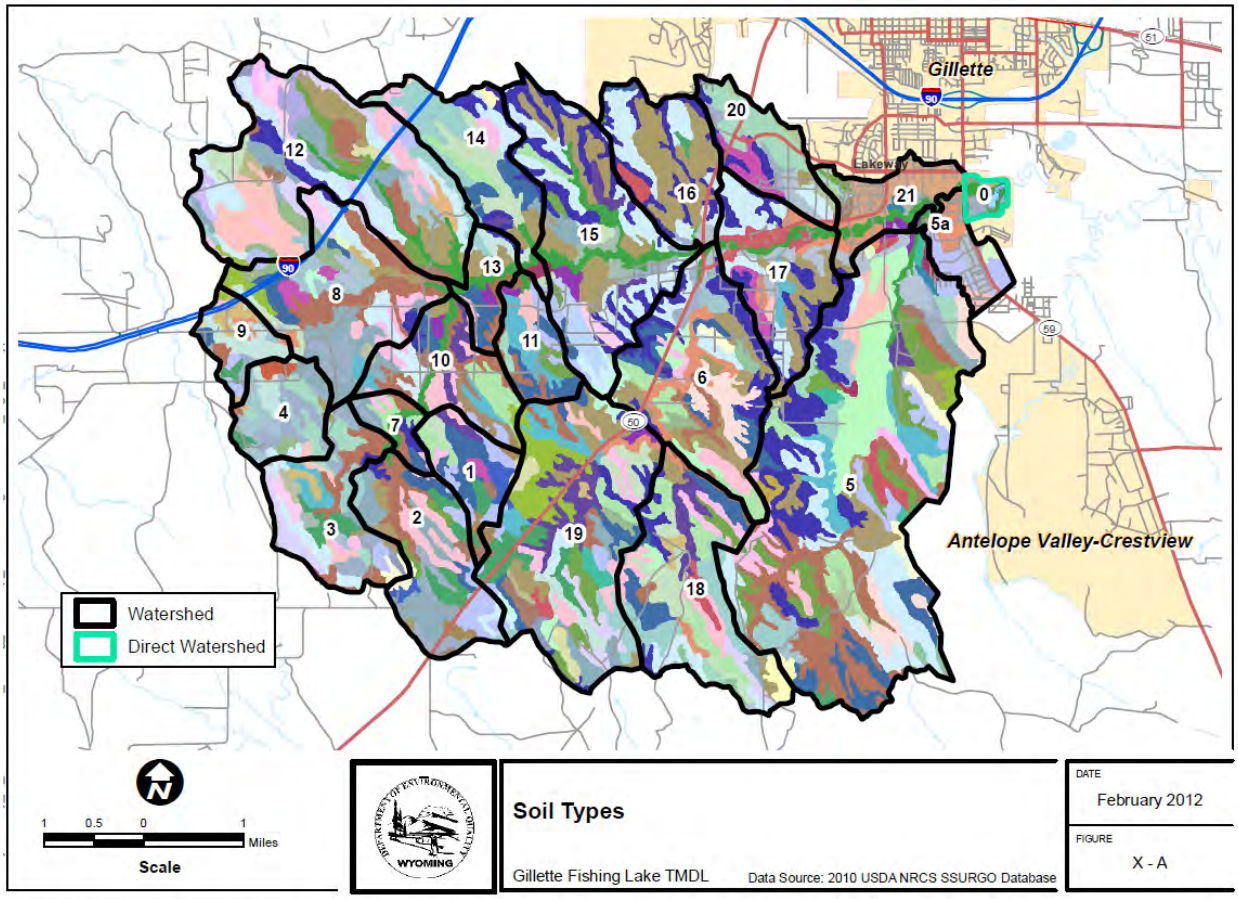
TABLE 3 – GENERAL INFORMATION FOR GILLETTE FISHING LAKE

Hydrologic Unit Code	101202010601
303(d) Waterbody ID	WYBF101202010601_01
Year Established	1949
Latitude (near center of lake)	44° 15’ 53.147”N
Longitude (near center of lake)	105° 29’ 16.453”W
Pool Elevation (feet)	4519
WDEQ/WQD Waterbody	2ABww
Tributaries	Donkey Creek
Receiving Water	Donkey Creek
Lake Surface Area (acres)	25
Maximum Depth (feet)	10.4
Mean Depth (feet)	5.3
Original Lake Volume (acre-feet)	118
Current Lake Volume (acre-feet)	92
Watershed Area (acres)	25,717
Watershed/Lake Area Ratio	1,000:1
Estimated Annual Inflow to Lake (acre-ft/year)	666
Estimated Annual Outflow to Lake (acre-ft/year)	728

The entire Gillette Fishing Lake watershed is located in the Northwestern Great Plains Level III ecoregion (Omernik and Gallant, 1987) and the Powder Basin Level IV ecoregion (Chapman et al, 2004). The northern part of Campbell County lies along the eastern edge of the Powder River structural basin, on the flank of the Black Hills. The geological formations within this area include the Lance, Fox Hills, Fort Union, and Wasatch Formations. Coal deposits underlie much of this area. The soils in this area are generally described as predominately to moderately deep to very deep fine sandy loams, loams, and clay loams (USDA NRCS, 2007). Figure 3A and 3B display and list the NRCS soil types within the Gillette Fishing Lake watershed.

The only regulated point sources within the Gillette Fishing Lake watershed are coal bed methane (CBM) extraction points. A location map is located in appendix B. Wyoming Pollutant Discharge Elimination System (WYPDES) program regulates discharges from these outfalls through permits issued by the program.

FIGURES 3A AND 3B – SOIL TYPES WITHIN THE GILLETTE FISHING LAKE WATERSHED



Soil Name
Aridic Ustorthents, saline, 0 to 4 percent slopes
Arvada, thick surface very fine sandy loam, 0 to 6 percent slopes
Arvada, thick surface-Arvada-Slickspots complex, 0 to 6 percent slopes
Arwite fine sandy loam, 0 to 6 percent slopes
Arwite fine sandy loam, 6 to 15 percent slopes
Arwite-Elwop fine sandy loams, 0 to 6 percent slopes
Arwite-Elwop fine sandy loams, 6 to 15 percent slopes
Arwite-Vonalf fine sandy loams, 6 to 15 percent slopes
Bowbac-Worf fine sandy loams, 3 to 15 percent slopes
Cromack-Fairburn-Ucross complex, 3 to 20 percent slopes
Cushman-Shingle loams, 6 to 15 percent slopes
Cushman-Worf loams, 3 to 15 percent slopes
Deekay loam, 0 to 6 percent slopes
Deekay-Moorhead loams, 0 to 6 percent slopes
Deekay-Moorhead loams, 6 to 15 percent slopes
Deekay-Oldwolf loams, 0 to 6 percent slopes
Deekay-Oldwolf loams, 6 to 15 percent slopes
Deekay-Ziggy loams, 0 to 6 percent slopes
Echeta clay loam, 0 to 6 percent slopes
Echeta-Cromack clay loams, 6 to 15 percent slopes
Felix clay, ponded, 0 to 2 percent slopes
Heldt-Bidman complex, saline, 0 to 3 percent slopes
Ironbutte-Deekay-Moorhead association, 3 to 30 percent slopes
Ironbutte-Fairburn-Mittenbutte complex, 6 to 40 percent slopes
Ironbutte-Ironbutte, thin solum channery loams, 6 to 40 percent slopes
Jayem fine sandy loam, 6 to 20 percent slopes
Jaywest loam, 0 to 6 precent slopes
Jaywest-Moorhead loams, 0 to 6 percent slopes
Jaywest-Spottedhorse loams, 0 to 6 percent slopes
Julesburg fine sandy loam, 0 to 6 percent slopes
Keyner fine sandy loam, 0 to 6 percent slopes
Leiter-Cromack clay loams, 3 to 15 percent slopes
Lismas-Sabatka-Badland complex, 3 to 45 percent slopes
Moorhead clay loam, 0 to 6 percent slopes
Moorhead loam, 0 to 6 percent slopes
Moorhead-Leiter clay loams, 0 to 6 percent slopes
Moorhead-Leiter clay loams, 6 to 15 percent slopes
Moskee fine sandy loam, 0 to 6 percent slopes
Muleherder-Ironbutte channery loams, 3 to 40 percent slopes
Nuncho loam, 0 to 6 percent slopes
Oshoto-Moorhead loams, 0 to 6 percent slopes
Pitchdraw-Ashollow-Niobrara complex, 3 to 30 percent slopes
Pits-Dumps complex
Platmak loam, 0 to 6 percent slopes
Rauzi sandy clay loam, 0 to 6 percent slopes
Rauzi-Elwop fine sandy loams, 2 to 10 percent slopes
Recluse loam, 0 to 6 percent slopes
Renohill-Worfka clay loams, 3 to 15 percent slopes
Samday-Savageton clay loams, 3 to 15 percent slopes
Samday-Shingle-Badland complex, 10 to 45 percent slopes
Shingle-Taluce complex, 3 to 30 percent slopes
Shingle-Worf loams, 3 to 30 percent slopes
Theedle-Turnercrest-Kishona complex, 3 to 15 percent slopes
Ucross loam, 1 to 9 percent slopes
Ucross-Iwait loams, 0 to 6 percent slopes
Ucross-Iwait-Fairburn loams, 3 to 30 percent slopes
Urban land-Deekay-Moorhead complex, 0 to 6 percent slopes
Vonalf fine sandy loam, 0 to 6 percent slopes
Vonalf-Xema fine sandy loams, 3 to 10 percent slopes
Wyarno-Ulm clay loams, 0 to 6 percent slopes
Ziggy-Iwait loams, 0 to 6 percent slopes
Ziggy-Iwait loams, 6 to 15 percent slopes
Ziggy-Ucross-Oldwolf loams, 3 to 15 percent slopes
Water
WYOMING
Soil Types - Legend
Gillette Fishing Lake TMDL
DATE
February 2012
FIGURE
X - B

3.0 WATER QUALITY CONDITIONS, PROBLEM IDENTIFICATION, AND PAST POLLUTANT CONTROL EFFORTS

Gillette Fishing Lake provides an important public fishing opportunity in Campbell County. The Wyoming Game and Fish Department (WGFD) typically stock the lake each spring with 6,000 to 8,000 catchable non-native rainbow trout (CCCD and City of Gillette, 2005). Stocking of Gillette Fishing Lake occurs each year due to uncaught fish dying over the winter. Severe winter kills occurred in 1963, 1992 and 2001 (Nikirk, 2009). Approximately 100 fish died in a fish kill on August 28th, 2009. The dissolved oxygen (DO) measurement throughout the water column during the 2009 fish kill was less than one milligram per liter (mg/L).

Sediment has accumulated in Gillette Fishing Lake since the lakes' creation. WGFD documented the dredging of the lake for the first time in a Fish Division Progress report (WGFD, 1976). The report discusses that there was considerable amounts of organic muck and aquatic vegetation, especially cattails, present prior to the dredging and that winter fish kills occurred nearly every year (WGFD, 1976). Dredging operations in 1973 removed approximately 32,808 cubic yards of silt and organic muck, adding 20.34 acre-feet to the capacity of the lake (WGFD, 1976). The lake was dredged a second time in 1984 and stocked with grass carp to control plants (CCCD and City of Gillette, 2005).

The City and Campbell County Conservation District (CCCD) recognized the need to dredge Gillette Fishing Lake in 1993. Before undertaking dredging for the third time in 20 years, these entities decided to conduct a study to evaluate water quality in the Gillette Fishing Lake watershed. The intent of the study was to determine the causes of the deterioration of fisheries habitat in the lake.

In December 1993, CCCD submitted a 205j proposal to the State (WDEQ/WQD) for the study and funding. Proposal approval allowed for the collection of sediment and phosphorus data June 1994 through August 1995. The results of the study indicated that the primary sources of sediment were the two subbasins directly upstream of Gillette Fishing Lake. These two subbasins account for 2 percent of the total watershed area above the lake. Due to the nature of the land management and characteristics of the land surface, predominately urban, these two subbasins contribute largely to the peak flows and sediment discharge. However, they deliver an insignificant amount of total water discharge and do nothing to the base flows to the lake due to their size and quick response times (ICD, 1995).

The study also identifies that the mean phosphorus concentration was at a level well into the eutrophic category, and at times, was at hypereutrophic levels. The study concluded that the primary deterrent to water quality is suspended sediment discharge and deposition. The study also noted that sediment particles are the probable transport mechanism for phosphate. A reduction of the sediment and phosphate will enable the lake to clear up, have lower temperatures, increase dissolved oxygen, and provide better aquatic habitat for fish (ICD, 1995). Therefore, WDEQ/WQD listed Gillette Fishing Lake as a threatened waterbody for both sediment and phosphate on the 1996 §303(d) list and every subsequent §303(d) list.

Since the 205j study, the City applied two approaches for reducing the sediment load from stormwater drainage. The first approach is a street sweeping program on roadways directly adjacent to Gillette Fishing Lake to prevent scoria, igneous rock and other aggregate particles

applied to the city streets during times of winter and icy road conditions from being carried into the lake during runoff events. The second approach is installation of four Stormceptors within the Donkey Creek drainage directly leading to Gillette Fishing Lake. These Stormceptors capture and remove sediment, oil and grease from the stormwater prior to it reaching Gillette Fishing Lake.

The City and CCCD also recognizes the reduction of sediment and phosphorus to Gillette Fishing Lake will not resolve without the active support of the City's citizens. Therefore, CCCD has provided continual education on the effects of nonpoint source pollution within the watershed. Education occurs through video and commercials production and distribution to highlight the effects of nonpoint source pollution on Donkey Creek and Gillette Fishing Lake.

In 2005, CCCD wrote a Gillette Fishing Lake Water Quality Improvement Plan (the Plan). The purpose the Plan was to focus resources on achieving the designated uses and for the removal of Gillette Fishing Lake from the §303(d) list. The plan outlines the intended and completed improvements conducted by the City to improve Gillette Fishing Lake in order to reduce sedimentation and nonpoint source pollution. The plan outlines previously mentioned improvements as well as the Gillette Fishing Lake Bank Stabilization and Dredging project. These improvements plans have been included in the City's Capital Improvement Plan (CIP). The City applied for CWA §319 grant funds to implement lake improvements. A governor-appointed task force, Nonpoint Source Task, approved funding for the project. The grant stipulated that the completion of an EPA watershed-based plan or TMDL occur prior to any lake improvements. The City initiated the Gillette Fishing Lake TMDL project in 2008. Sampling and TMDL development was the intent of the 2008 project.

4.0 DESIGNATED USES AND APPLICABLE WATER QUALITY CRITERIA

Gillette Fishing Lake has a 2ABww classification (WDEQ/WQD, 2011). WDEQ/WQD regulations for class 2AB waters are as follows (WDEQ/WQD, 2007):

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

Gillette Fishing Lake receives runoff from and drains into Donkey Creek, a tributary to the Belle Fourche River in the Missouri River Drainage Basin. Donkey Creek has a classification of 3B. Class

3B waters are intermittent and ephemeral streams with the designated uses of aquatic life other than fish, recreation, wildlife, industry, agriculture and scenic value.

In 1996, Gillette Fishing Lake was included on Wyoming's §303(d) list of impaired waters as threatened for support of cold water fisheries and aquatic life other than fish due to siltation and phosphate. Wyoming's 2008 §303(d) list continued to contain the lake based on impairments to aquatic life other than fish and cold water fisheries uses. A Use Attainability Assessment (UAA), conducted in 2011, changed Gillette Fishing Lake classification from 2AB cold water fishery to a 2AB warm water fishery. Although the classification changed, the aquatic life other than fish and warm water fisheries uses continue to be impaired.

Applicable water quality standards for Gillette Fishing Lake are as follows:

- Fisheries – Section 3(b) of Chapter 1 states that the fisheries use includes water quality, habitat conditions, spawning and nursery areas, and food sources necessary to sustain populations of game and nongame fish. This use does not include the protection of exotic species that are designated "undesirable" by the Wyoming Game and Fish Department or the U.S. Fish and Wildlife Service within their appropriate jurisdictions.

- Aquatic Life Other than Fish – Section 3(g) of Chapter 1 states that the aquatic life other than fish use includes water quality and habitat necessary to sustain populations of organisms other than fish in proportions which make up diverse aquatic communities common to the waters of the state. This use does not include the protection of insect pests or exotic species which may be considered "undesirable" by the Wyoming Game and Fish Department or the U.S. Fish and Wildlife Service within their appropriate jurisdictions.

- The State of Wyoming has not developed specific criteria for nutrients. Some of the narrative criteria in Wyoming's water quality standards can apply to phosphorus and sediment. For this report, narrative and numeric criteria that are applicable to the identified impaired uses and causes for the impairments (sediment and phosphorus) are as follows: Fisheries - Wyoming has three separate sub-categories for the fisheries use: cold water game fisheries, warm water game fisheries and nongame fisheries. Fisheries use support is evaluated using the numeric criteria listed in Sections 24, and appendices B, C and D and narrative criteria in Sections 15, 16, 28 and 32 of Chapter 1. The acute aquatic life criteria listed in appendix B constitute the highest concentration of a physical or chemical parameter to which an aquatic community can be exposed for one hour without deleterious effects. Chronic aquatic life criteria represent the highest average concentration of a physical or chemical parameter to which an aquatic community can be exposed to for four days without deleterious effects. The average concentration of four evenly spaced samples is preferred by WDEQ for evaluating acute (i.e. one sample every 15 minutes) and chronic (i.e. one sample per day) criteria for use support determinations. However, it is generally assumed that a single sampling event represents the water quality condition for these longer time periods. WDEQ also uses the aquatic life other than fish as an additional surrogate measure of fisheries designated use support. Evaluations of numeric criteria for non-toxic pollutants may or may not require the use of credible data; however, when narrative criteria are evaluated to determine use support, credible data are required.

- Aquatic life other than fish numeric criteria are listed in Section 26, appendix B (listed under aquatic life acute and chronic values) and appendix C of Chapter 1. The acute aquatic life criteria listed in appendix B constitute the highest concentration of a physical or chemical parameter to which an aquatic community can be exposed for one hour without deleterious effects. Chronic aquatic life criteria represent the highest average concentration of a physical or chemical parameter to which an aquatic community can be exposed to for four days without deleterious effects. The average concentration of four evenly spaced samples is preferred by WDEQ for evaluating acute (i.e. one sample every 15 minutes) and chronic (i.e. one sample per day) criteria for use support determinations. However, it is generally assumed that a single sampling event represents the water quality condition for these longer time periods.

- WDEQ recognizes that fish populations and communities can be influenced by factors such as stocking rates, fishing pressure, stream connectivity and competitive displacement via invasive species. However, because WDEQ does not directly study fish communities while conducting monitoring, the influence of these factors is often unknown. WDEQ regularly uses WGFD sampling records to determine current and historic fish distributions.

- Narrative criteria for the aquatic life other than fish use can be found in sections 15, 16, 21, 24, 28 and 32 of Chapter 1. These narrative criteria are primarily evaluated for perennial streams using the Wyoming Stream Integrity Index (WSII) (Harget 2011) and the River Invertebrate Prediction and Classification System (RIVPACS) (Harget 2012). The results of these two models are combined into a single narrative rating derived from a decision matrix. WDEQ may also use other bioassessment methods, such as multi-habitat sampling (Harget 2011) or paired watershed studies to determine aquatic life other than fish use support for waters that are perennial, ephemeral, intermittent or low gradient. Aquatic life other than fish use support determinations are used by WDEQ as surrogate measures of fisheries, agricultural, wildlife and industrial designated uses. Evaluations of numeric criteria for non-toxic pollutants may or may not require the use of credible data; however, when narrative criteria are evaluated to determine use support, credible data are required.

Wyoming uses the above narrative and numeric criteria to determine if designated uses are attained. Numeric criteria are typically evaluated by collecting the chemical water quality data for each specific criterion. Chemical, physical and biological data are collected and evaluated using a weight of evidence approach with narrative standards to determine if uses are protected. Wyoming also uses surrogates to determine if other uses are attained. The aquatic life other than fish use is used as a surrogate to determine if the fisheries, wildlife, agriculture and industry uses are being protected. The aquatic life other than fish use is as a surrogate to determine if wildlife, agriculture and industry uses attainment and will further support the restoration and protection of the fisheries use for this TMDL report.

Wyoming DEQ determines the attainment of the aquatic life other than fish use by evaluating the associated narrative criteria, listed above, using Worming Stream Integrity Index (WSII) (Harget, 2011) and River Invertebrate Prediction and classification System (RIVPACS) (Hargett, 2012) for perennial streams. Such methods are not useful in lakes due to the heavy reliance on the health of aquatic invertebrates. Surveys of invertebrates have not occurred in Gillette Fishing Lake and reference sites are unavailable. This will preclude the use of invertebrates as a target from

determining the attainment of aquatic life other than fish use. Algae are the targeted aquatic life that is contributing to issues in the lake.

Gillette Fishing Lake has continued to be included on the Wyoming §303(d) list of impaired waters based on observations from WDEQ/WQD, the City and CCCD. WDEQ/WQD has determined that all available information only indicates that Gillette Fishing Lake does not support fisheries and aquatic life other than fish uses due to sediment accumulation at the bottom of the lakebed and the eutrophic to hypereutrophic conditions caused by the overabundance of phosphorus associated with sediment.

All other water quality standards applicable to Gillette Fishing Lake are in Chapter 1 of Wyoming's Water Quality Rules and Regulations (2007). Drinking water, recreation, scenic value, and fish consumption uses have not shown any indication of impairment. Gillette Fishing Lake is not a source for drinking water. Wyoming intends on removing the drink water use. The recreation use and criteria are addressed in a separate TMDL.

Scenic value is currently not assessed in Wyoming and there is no numeric or narrative standards in Chapter 1 of Wyoming's Water Quality Rules and Regulations. The scenic value will be addressed when criteria are developed and added to chapter 1.

Fish consumption evaluation occurs by determining if there are any substances causing unpalatable flavors or hazards to humans in the fish itself. Health hazards and unpalatable flavors are not typically caused by sediment and phosphorous in fish. WDEQ/WQD Monitoring Program's will use the *Surface Water Monitoring Strategy 2010-2019* (WDEQ, 2010) to evaluate other uses based on the planned schedule.

5.0 POLLUTANT SOURCES

This TMDL identifies two categories of pollutant sources for sediment and TP. Nonpoint and point sources are the two source categories of pollution. The following is a brief discussion of both sources:

- **Nonpoint Sources** – The largest contribution of sediment and phosphorus loading to Gillette Fishing Lake is delivered into the lake by direct runoff from the direct watershed and adjacent subbasins with urban, construction, roadways and Wyoming Big Sage Brush land uses. A portion of the phosphorus loading is internal.
- **Point Sources** – The only point sources in the Gillette Fishing Lake watershed are CBM wells. The States WYPDES program regulates these dischargers. The discharged water is not contributing to the impairments in Gillette Fishing Lake.

6.0 INFORMATION AND ASSUMPTIONS UTILIZED FOR THIS TMDL

The analysis performed and presented in the remaining sections of this document use the best available information. The available information and the assumptions in this TMDL are as follows:

- Gillette Fishing Lake inlet and outlet sampling – Minimal water quality sampling was completed. Only one year of sampling occurred due to funding limitations. This sampling yielded a minimum amount of data. The limited sampling did provide enough information to become knowledgeable about the watershed and determine the sources of the pollutant.
- Point Source Discharges – For the point source discharges, many of these sites flow into stock ponds or ephemeral drainages, which are hydrologically disconnected. Due to the disconnection, these sites do not contribute any of the loads of either sediment or TP to Gillette Fishing Lake.
- Hydrologic Disconnection – Throughout the watershed, there are numerous ponds or impoundments along Donkey Creek and its tributaries. These impoundments create hydrologic disconnections, as noted in the 205j report. In addition, several permits are impoundment-type permits and do not allow discharge into surface waters except during extreme events.

  The effects of each subbasin on Gillette Fishing Lake vary tremendously. With the location of several manmade dams on Donkey creek and the shallow gradient, sediment transport is minimal in the upper and middle reaches of the creek. The last dam before flow enters the lake is just below the Barlow sampling site (ICD, 1995). After this final dam, flow remains sluggish due to the gradient of less than 0.1 percent (ICD, 1995).

  Consideration of disconnection of upper and middle reaches occurs throughout this document. Based on these observations from the 205j report, the contributions of the pollutants from the subbasins upstream of the manmade dams versus the contributions of the subbasins downstream of the dams is minimal.
- Channel Stability – The 205j report measured three reaches on Donkey Creek for channel stability. The findings of the 205j report note that the channels are in good condition and remain stable throughout the entire creek. Incision and channel erosion along the stream course is not degrading water quality (ICD, 1995). Therefore, the focus was on sheet and rill erosion based on land uses.
- The 1984 dredging assumes to have removed all of the accumulated sediment, resetting the capacity of the lake to the original lake water volume. This assumption causes the sediment accumulation rate to be higher because rarely does dredging remove all accumulated sediment. This is a conservative assumption but is not over conservative based on the results of the estimated RUSLE sediment yield and lake trap efficiency rates. It provides for additional MOS ensuring that conditions in the lake will trend more towards a mesotrophic or eutrophic lake.

7.0 DATA SOURCES

Data sources used for the Gillette Fishing Lake TMDL include:

- Lake water quality sampling
- Stream water quality sampling
- Flow measurements at the inlet and outlet
- Sediment sampling at the inlet and survey of the deposited sediment in the lake
- Wyoming Game and Fish sampling

7.1 LAKE SAMPLING

Several water quality parameters were collected at three sampling sites on Gillette Fishing Lake (L1, L2 and L3) from October 2008 through September 2009 as a part of this project. Figure 4 displays sampling locations. Seasonality is based on dry fall, wet spring, wet summer and dry summer. Tables 4, 5 and 6 display the results of the sampling. A total of fifteen samples were taken at site L1, L2 and L3. These samples are integrated samples representing the entire vertical column of water throughout the lake. Appendix A displays the blanks and duplicates collected for quality assurance.

7.2 STREAM SAMPLING

Donkey Creek sampling of occurred from October 2008 through September 2009 at the inlet (sampling site T1) and outlet (sampling site T2) of Gillette Fishing Lake (Figure 4). Stream sampling focused on different points of the hydrograph. Samples were collected during ascending, peak, and descending flows. Although every effort was made to collect the inlet and outlet samples during the same sampling event, in some cases, the inlet or outlet was not flowing. Therefore, a sample was taken at only one of the sampling sites during that sampling event. The results for sampling sites T1 and T2 are presented in Tables 7 and 8, respectively. The City collected 18 samples from sampling sites T1 and T2. Appendix A contains the blank and duplicate samples collected for quality assurance.

FIGURE 4 –SAMPLING SITES

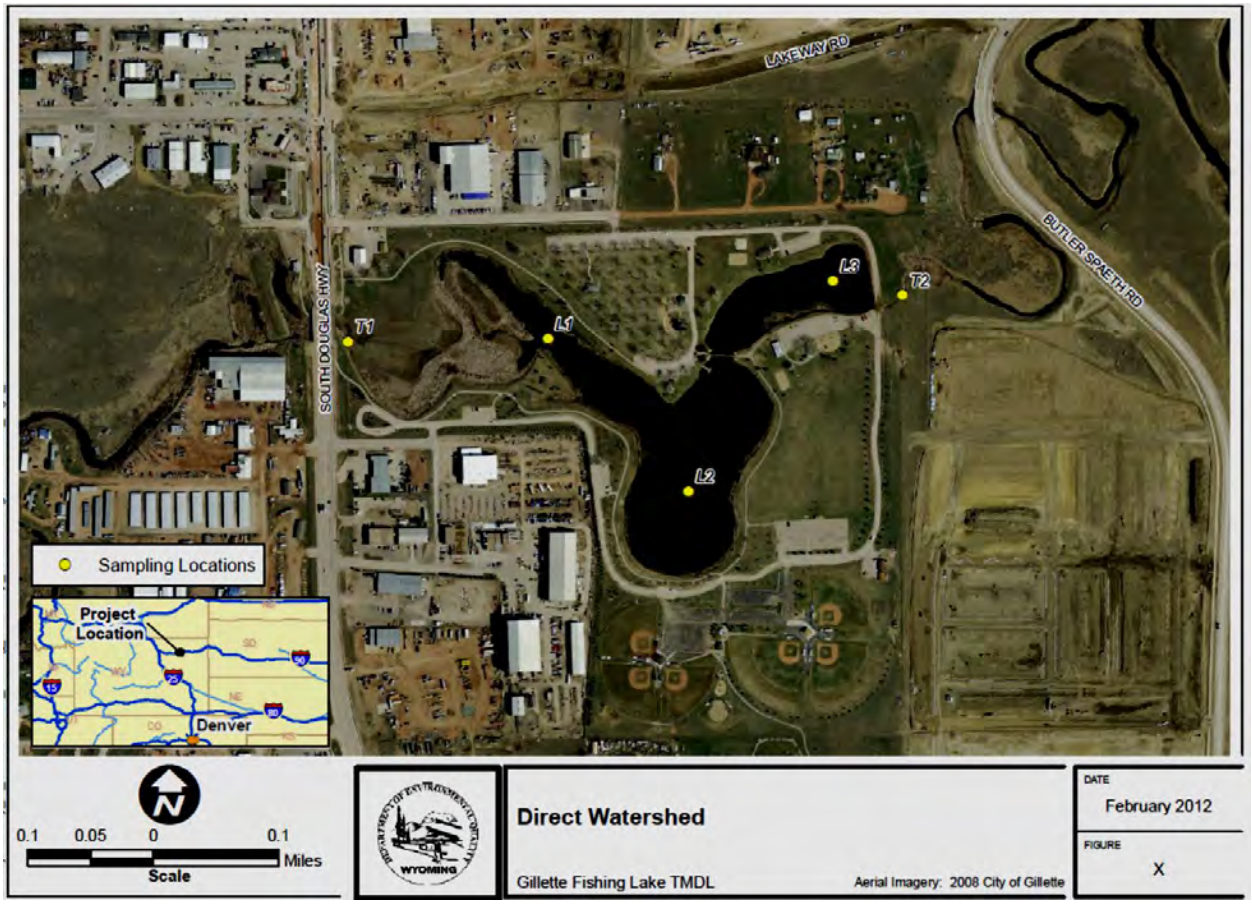


TABLE 4 – SAMPLING SITE L1 (LOCATION: 44° 15' 59.472" N/ 105° 29' 24.624" W)

Parameter	10/24/08	4/21/09	6/19/09	7/22/09	8/20/09
Time	12:09 PM	11:05 AM	9:42 AM	2:30 PM	10:55 AM
Air Temperature (°C)	10.00	19.00	19.00	32.00	18.00
Total Depth (m)	2.00	1.60	1.50	1.50	1.70
Water Temperature (°C)					
Surface	6.04	10.00	18.36	25.27	17.72
0.50 m	6.05	10.01	18.19	22.18	17.69
1.00 m	6.05	9.98	17.69	21.14	17.64
DO (mg/L)					
Surface	8.27	9.86	7.66	16.30	6.74
0.50 m	8.24	9.54	7.68	15.34	6.63
1.00 m	7.95	9.57	7.07	6.34	6.51
pH					
Surface	7.99	7.58	8.68	8.89	8.21
0.50 m	7.97	7.40	8.52	8.67	8.27
1.00 m	7.94	7.42	8.34	8.09	8.29
pH Integrated Sample	7.89	7.98	8.68	8.84	8.39
Turbidity (NTU)	5.58	6.24	11.30	13.60	11.20
Secchi Depth (m)	1.00	0.72	0.69	0.38	0.52
Chlorophyll-a (mg/m^3)	14.00	22.00	33.00	230.00	110.00
Nitrate (mg/L)	ND	ND	ND	ND	ND
Nitrite (mg/L)	ND	ND	ND	ND	ND
Nitrate+Nitrite (mg/L)	ND	ND	ND	ND	ND
TSS (mg/L)	9.00	10.00	11.00	42.00	30.00
Orthophosphate as P (mg/L)	0.02	0.02	0.02	0.05	0.16
Total Phosphorus as P (mg/L)	0.07	0.07	0.08	0.30	0.28
Notes: ND=Nondetect					

TABLE 5 – SAMPLING SITE L2 (LOCATION: 44° 15' 59.147" N/ 105° 29' 16.453" W)

Parameter	10/24/08	4/21/09	6/19/09	7/22/09	8/20/09
Time	11:15 AM	12:00 PM	10:26 AM	3:30 PM	11:20 AM
Air Temperature (°C)	9.00	19.00	20.00	32.00	18.00
Total Depth (m)	2.00	2.00	2.00	2.00	2.20
Water Temperature (°C)					
Surface	5.84	10.57	19.04	25.14	18.24
0.50 m	5.82	10.55	18.84	24.40	18.23
1.00 m	5.82	10.45	18.70	21.58	18.22
1.5 m		10.32	18.20	20.68	18.19
DO (mg/L)					
Surface	8.78	11.05	8.87	13.60	8.12
0.50 m	8.53	10.93	8.89	14.96	8.22
1.00 m	8.52	10.94	8.70	10.56	8.04
1.50 m		10.98	7.00	2.71	7.90
pH					
Surface	8.20	8.13	8.36	8.74	8.53
0.50 m	8.12	8.13	8.36	8.76	8.58
1.00 m	8.05	8.13	8.36	8.43	8.63
1.50 m		8.12	8.27	8.00	8.64
pH Integrated Sample	8.12	8.18	8.68	8.65	8.68
Turbidity (NTU)	10.10	8.39	13.80	7.51	16.10
Secchi Depth (m)	0.75	0.72	0.64	0.53	0.43
Chlorophyll-*a* (mg/m^3)	11.00	47.00	46.00	67.00	200.00
Nitrate (mg/L)	ND	ND	ND	ND	ND
Nitrite (mg/L)	ND	ND	ND	ND	ND
Nitrate+Nitrite (mg/L)	ND	ND	ND	ND	ND
TSS (mg/L)	24.00	12.00	14.00	22.00	28.00
Orthophosphate as P (mg/L)	0.02	0.02	0.03	0.06	0.16
Total Phosphorus as P (mg/L)	0.09	0.07	0.08	0.22	0.41
Notes: ND=Nondetect					

TABLE 6 – SAMPLING SITE L3 (LOCATION: 44° 16' 1.915" N/ 105° 29' 8.116" W)

Parameter	10/24/08	4/21/09	6/19/09	7/22/09	8/20/09
Time	9:49 AM	12:50 PM	11:03 AM	3:45 PM	11:30 AM
Air Temperature (°C)	6.00	19.00	21.00	32.00	18.00
Total Depth (m)	2.30	1.80	2.70	2.90	2.80
Water Temperature (°C)					
Surface	5.88	10.58	20.00	26.16	18.69
0.50 m	5.88	10.51	19.41	22.10	18.69
1.00 m	5.88	10.46	18.93	20.94	18.66
1.50 m	5.87	10.27	18.12	20.64	18.57
2.0 m			17.42	20.52	18.00
2.5 m			16.04		
DO (mg/L)					
Surface	8.91	11.38	10.73	12.91	8.17
0.50 m	8.77	11.27	10.74	17.26	8.10
1.00 m	8.81	11.13	10.31	9.90	7.97
1.50 m	8.85	11.19	7.39	5.33	7.85
2.0 m			2.94	3.82	6.39
2.5 m			0.16		
pH					
Surface	8.15	8.29	8.64	8.00	8.63
0.50 m	8.15	8.24	8.68	8.86	8.64
1.00 m	8.13	8.24	8.70	8.49	8.65
1.50 m	8.12	8.24	8.56	8.28	8.64
2.0 m			8.26	8.16	8.55
2.5 m			8.03		
pH Integrated Sample	8.05	8.21	8.62	8.46	8.64
Turbidity (NTU)	7.77	6.08	13.00	10.06	11.40
Secchi Depth (m)	0.75	0.75	0.58	0.61	0.53
Chlorophyll-*a* (mg/m^3)	16.00	45.00	42.00	34.00	130.00
Nitrate (mg/L)	ND	ND	ND	ND	ND
Nitrite (mg/L)	ND	ND	ND	ND	ND
Nitrate+Nitrite (mg/L)	ND	ND	ND	ND	ND
TSS (mg/L)	13.00	8.00	14.00	15.00	25.00
Orthophosphate as P (mg/L)	0.02	0.02	0.03	0.06	0.16
Total Phosphorus as P (mg/L)	0.12	0.07	0.07	0.16	0.32
Notes: ND=Nondetect					

TABLE 7 – SAMPLING SITE T1-INLET (LOCATION: 44° 15' 59.581" N/ 105° 29'36.340" W)

Parameter	11/21/08	4/10/09	4/21/09	5/26/09	6/8/09	6/9/09	6/19/09	7/8/09	8/17/09
Staff Gauge (ft)	0.40	1.20	0.56	0.46	0.60	0.92	0.34	0.50	0.48
Time	11:49 AM	12:45 PM	2:20 PM	10:45 AM	12:00 PM	10:30 AM	12:45 PM	3:50 PM	3:05 PM
Air Temperature (°C)	4.00	9.00	21.00	14.44	21.80	14.80	22.00	27.00	18.00
Water Temperature (°C)	3.95	4.26	12.55	14.39	11.42	13.77	18.37	22.50	16.48
DO (mg/L)	8.87	10.06	8.93	3.88	4.29	3.54	7.24	3.89	2.41
pH	7.65	7.84	7.75	7.78	8.09	7.54	8.04	7.84	7.48
Turbidity (NTU)	7.03	26.30	5.78	9.40	5.92	9.44	5.59	4.52	10.73
Nitrate (mg/L)	0.1	0.20	ND	ND	0.10	0.10	ND	ND	ND
Nitrite (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND
Nitrate+Nitrite (mg/L)	0.1	0.30	0.10	ND	0.10	0.20	ND	ND	ND
TSS (mg/L)	10	11.00	ND	5.00	ND	6.00	ND	ND	ND
Orthophosphate as P (mg/L)	0.03	0.16	0.04	0.30	0.12	0.12	0.32	0.17	0.12
Total Phosphorus as P (mg/L)	0.05	0.24	0.08	0.42	0.17	0.14	0.38	0.23	0.18

TABLE 8 – SAMPLING SITE T2-OUTLET (LOCATION: 44° 16' 1.325" N/ 105° 29'4.121" W)

Parameter	10/23/08	11/13/08	4/10/09	4/21/09	5/26/09	6/8/09	6/9/09	7/8/09	8/17/09
Staff Gauge (ft)	0.96	0.94	1.84	1.3	0.94	1.14	1.22	1.16	0.98
Time	1:11 PM	9:15 AM	12:00 PM	15:05 PM	9:45 AM	10:59	9:40 AM	3:20 PM	2:30 PM
Air Temperature (°C)	11.00	7.00	9.00	22.00	12.00	19	20.50	27	18.00
Water Temperature (°C)	6.31	4.45	5.90	12.33	16.29	14.52	14.12	24.13	20.6
DO (mg/L)	10.63	10.00	17.21	10.93	8.17	9.31	10.58	9.97	8.41
pH	8.14	8.07	8.01	8.34	8.26	8.6	8.38	8.35	8.71
Turbidity (NTU)	5.85	4.94	13.40	8.09	9.1	15.5	13.6	7.4	12.5
Nitrate (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND
Nitrite (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND
Nitrate+Nitrite (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND
TSS (mg/L)	6	5	11.00	18	15	17	19	10	32
Orthophosphate as P (mg/L)	0.01	0.01	0.03	0.02	0.02	0.01	0.09	0.02	0.158
Total Phosphorus as P (mg/L)	0.06	0.06	0.07	0.06	0.08	0.09	0.11	0.09	0.393

7.3 FLOW MEASUREMENTS

Staff gages were installed at sampling sites T1 and T2 in order to monitor flow. The staff gage readings (water height in the channel) were taken by the City approximately twice a week from October 2008 to September 2009. The frequency of the readings also depended on the frequency of precipitation events. Additional readings were taken at different flow conditions in order to determine the range of the hydrograph. Staff gage readings were taken each time water quality samples were collected or discharge was measured.

USGS Station #06426130, Donkey Creek near Gillette, is located downstream of Gillette Fishing Lake (USGS 2008-2010). The USGS Station was used to estimate the annual flow at the inlet and outlet.

7.4 SEDIMENT SAMPLING

At sampling site T1, three samples of sediment were collected and tested for TP levels. Samples of newly deposited sediment were collected at the inlet of Gillette Fishing Lake. Samples collected throughout the project averaged approximately 230 mg/kg of TP (USDA NRCS, 2009).

The City conducted a sediment survey of Gillette Fishing Lake in July and August 2009 to determine the extent of sediment deposition at the bottom of the lake. Existing water depths and accumulated sediment thickness were measured along various cross section transects. The average end-area method is applied to each cross section in order to estimate the quantity of accumulated sediment and remaining existing water volume within each lake segment. Collected survey data are used to estimate original lake water volume, existing lake water volume and percent lake water volume loss. Table 9 contains the sediment survey.

The accumulated sediment at the bottom of Gillette Fishing Lake was core sampled in three locations throughout the lake to determine the particle size and water content of the sediment. The City collected the samples, and Energy Labs in Gillette conducted the characterization of the sediment. The sediment consisted primarily of fine-grained silt and clay sized particles (92 percent silt/clay and 8 percent fine sand). The water content of the sediment ranged from 28.9 percent to 58.5 percent with an average water content of 45.9 percent.

An estimate of the dry weight or bulk density of the sediment was determined to convert cubic yards to tons of accumulated sediment. According to the "Reservoir Sedimentation Handbook" (Morris and Fan, 1997), the average specific weight of submerged or saturated fine grained lake sediment consisting primarily of silt and clay (with a very small percentage of sand) ranged from 40 to 60 pounds per cubic foot. These estimates were based on an analysis of 800 reservoirs. Therefore, an average dry bulk soil density of approximately 50 pounds per cubic foot was selected as a conservative value for the Gillette Fishing Lake sediment due to the predominantly silt and clay composition. This dry bulk density estimation compared similarly to estimations based on U.S. Bureau of Reclamation (USBR) methods (USBR, 2006). Based on an average dry bulk density of 50 lbs per cubic foot or 0.675 tons per cubic yard, the estimated 41,540 cubic yards of accumulated sediment were converted to an estimated 28,040 tons (Table 9).

TABLE 9 – SEDIMENT SURVEY RESULTS AND CALCULATIONS

Description	Value
Original Lake Water Volume	190,150 cubic yards
Existing Lake Water Volume	148,610 cubic yards
Estimated Accumulated Sediment in the Lake	41,540 cubic yards
Conversion from pounds to cubic foot	50 pounds per cubic foot
Estimated Accumulated Sediment in the Lake	28,040 tons

7.5 FISH SPECIES PRESENT IN GILLETTE FISHING LAKE

Gillette Fishing Lake is an important fishery located within an urban setting. WGFD annually stocks rainbow trout in Gillette Fishing Lake in an effort to encourage Gillette residents to enjoy fishing, and it will continue to do so regardless of the lake's classification. Gillette Fishing Lake has the characteristics of a warm water fishery (e.g., black bullhead, walleye, higher temperatures, shallow depth, and low dissolved oxygen). Table 10 displays the fish communities found in Gillette Fishing Lake according to WGFD (2010).

TABLE 10 – FISH SURVEY RESULTS IN GILLETTE FISHING LAKE

Year	Fish Species in Gillette Fishing Lake by Year
1978	Carp, Fathead Minnow, Bullhead, Rainbow Trout (stocked),Walleye
1987	Rainbow Trout (stocked), Black Bullhead, Common Carp, Grass Carp (stocked)
1988	Rainbow Trout (stocked), White Sucker, Black Bullhead, Green Sunfish, Common Carp, Yellow Perch, Rock Bass, Grass Carp (stocked)
1989	Grass Carp (stocked), Common Carp, Goldfish, Walleye, Rainbow Trout (stocked), Channel Catfish, Yellow Perch, White Crappie, Black Bullhead, Fathead Minnows. White Sucker, Green Sunfish, Rock Bass
1998	Black Bullhead, Goldfish, Green Sunfish, Rainbow Trout (stocked), White Sucker
2000	Black Bullhead, Green Sunfish, White Sucker, Largemouth Bass, Goldfish, Common Carp, White Crappie, Rainbow Trout (stocked), Channel Catfish, Grass Carp, Walleye
2001	Black Bullhead, Goldfish, Rainbow Trout (stocked)
2003	Black Bullhead, Rainbow Trout (stocked), Fathead Minnow, Green Sunfish, Yellow Perch
Reference: WGFD, 2010. Note: The collection methods and the biomass of the species vary from year to year.	

8.0 CRITICAL CONDITION AND TEMPORAL VARIATION

According to 40 CFR 130.7(c) (1), the critical condition must be taken into account when developing TMDLs. The "critical conditions" are the conditions when the physical, chemical, and biological characteristics of the receiving water or environment interact with the pollutant to produce the greatest potential adverse impact on the existing designated use. The intent of this requirement is to ensure that the water quality of the receiving water is protected during times when it is most vulnerable.

In most lakes impacted by excessive nutrient and sediment loading, critical conditions typically occur during the ice-free months (typically the growing season, or April through November). During these months, sediment and flow conditions, sediment re-suspension, and phosphorus loading are most likely to create conditions that result in summer and winter fish kills. In addition, the 205j report noted that most of the sediment enters the lake in the spring and early summer (ICD, 1995). Therefore, in the TMDL calculations, the annual averages incorporate only the ice-free conditions.

The existing and target sediment and phosphorus loads for Gillette Fishing Lake are expressed primarily as annual averages. The models used to calculate the existing and target sediment and phosphorus loads use monthly flow, accumulated sediment, and phosphorus concentrations to calculate average annual sediment and phosphorus loading.

9.0 LINK BETWEEN POLLUTANTS AND DESIGNATED USES

9.1 PHOSPHORUS

Gillette Fishing Lake currently displays characteristics of eutrophication and hypereutrophication. These characteristics are large algal blooms, excessive beds of aquatic plants present during the growing season (April to August), and fish kills.

WGFD has recorded numerous fish kills at Gillette Fishing Lake, and in some cases, over 1,000 trout died, as well as green sunfish and fathead minnows (WGFD, 2010). Fish kills can occur during summer and winter months.

Numeric nutrient criteria are unlike typical criteria in that nutrients do not follow the typical dose-response relationships like toxics, metals, and pesticides. Phosphorus is an essential nutrient for all life forms and is often the limiting nutrient in freshwater systems. Lakes and reservoirs serve as excellent sediment traps as phosphorus-containing particles settle and accumulate in the bottom. Phosphorus stored in the top layer of the bottom sediments of lakes and reservoirs is subject to bioturbation by benthic invertebrates and chemical transformations by water chemistry interactions. The reducing conditions of the hypolimnion often experienced during the summer months in high productivity lakes and reservoirs may stimulate the release of phosphorus from the benthos through a process called diagenesis. The combined effects of watershed and benthic phosphorus loading often stimulate blooms of phytoplankton and blue-green algae. The excessive algae caused by excessive phosphorous are causing the impairments to the aquatic life other than fish and fisheries uses.

In temperate North American lakes, phosphorus and nitrogen are typically the nutrients that trigger algal blooms and growth of macrophytes (that is, phosphorus is the limiting algal nutrient). Analysis between TP, chlorophyll *a*, and secchi depth occurred to determine if elevated phosphorus concentrations are triggering algal blooms and decreased visibility in the lake. The TP and chlorophyll *a* relationship, the chlorophyll *a* and secchi disk relationship, and the TP and secchi depth relationship display high coefficients of determination, which can suggest strong correlations (see R-squared values in Figures 5 through 7). Elevated TP, chlorophyll a, and shallower secchi disk readings are all relevant indicators of an aquatic life other than fish use impairment.

The confidence limits in Figures 5, 6, and 7 show a band of variability, which can be attributed to the small sample size and short time period over which those samples were collected. Figure 5 shows the chlorophyll *a* plotted as a function of TP. Figure 5 displays a relationship between three of the samples collected with two outliers. Although variability exists, the plot demonstrates the general trend of increasing TP and increasing chlorophyll a. Figure 6 shows a trend of decreasing water clarity with increasing chlorophyll *a* concentrations. Figure 7 shows secchi depth plotted as a function of TP and displays the least correlation of the three relationships. However, despite previously mentioned variability, the correlation between the parameters is relatively high and confirms the influence of TP on both algal productivity and water clarity.

Nutrients such as phosphorus can stimulate the growth of algae, facilitating a decrease in DO concentrations when the algae decompose. Actively growing algae produce excess DO, but when excessive amounts of algae die off and decompose in deeper waters, microbial respiration (that is, digestion of the dead algal matter) uses DO. In lakes receiving large amounts of organic matter from the watershed (for example, plant materials and animal wastes), oxygen production and oxygen consumption are not balanced, and low DO can become even more of an issue (Michaud, 1991), thereby stressing the fish population present in a lake.

Under hypereutrophic conditions, die-offs of excessive algae and macrophytes can cause severe oxygen depletion, and entire fish populations can be lost to a summer fish kill (MPCA, 2005). Such summer anoxia can also lead to an increased release of phosphorus from sediments that can fuel algal blooms when mixed with the upper zone of the lake, perpetuating a cycling of algal bloom and die off. The cycle of increasing phosphorous, excessive algal growth, excessive macrophyte growth, die off of algae, DO consumption due to die off of algae, and fish kills are the links to the impairments of the aquatic life other than fish and fisheries uses. The relationship in figures 5, 6 and 7 between TP and indicators of algal growth (higher Chlorophyll a and lower secchi disk depth readings) demonstrate impairment to the aquatic life other than fish use. Therefore, there is a link between TP and the aquatic life other than fish use(due to excess growth of algae)which causes excessive DO consumption (due to algae die off) causing impairments to the fisheries use in Gillette Fishing Lake.

FIGURE 5 – TOTAL PHOSPHORUS AND CHLOROPHYLL A RELATIONSHIP IN GILLETTE FISHING LAKE

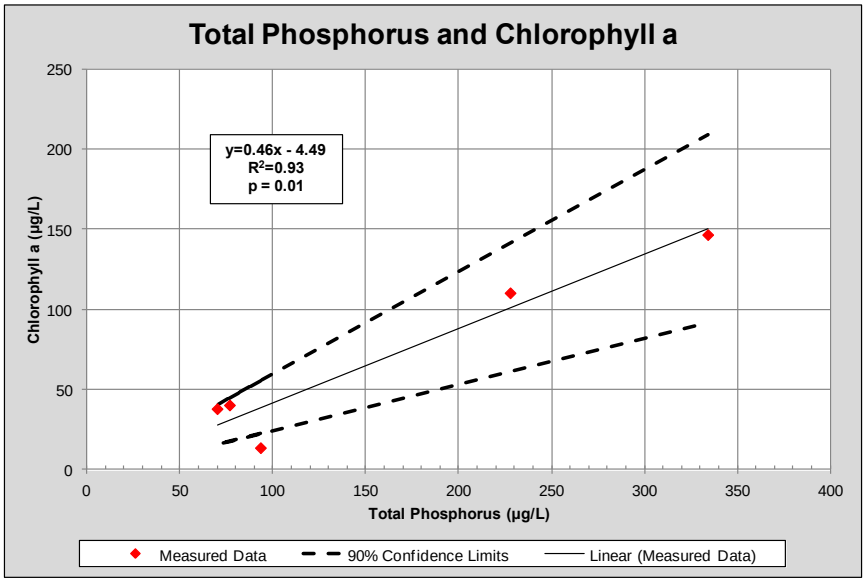


FIGURE 6 – CHLOROPHYLL A AND SECCHI DEPTH RELATIONSHIP IN GILLETTE FISHING LAKE

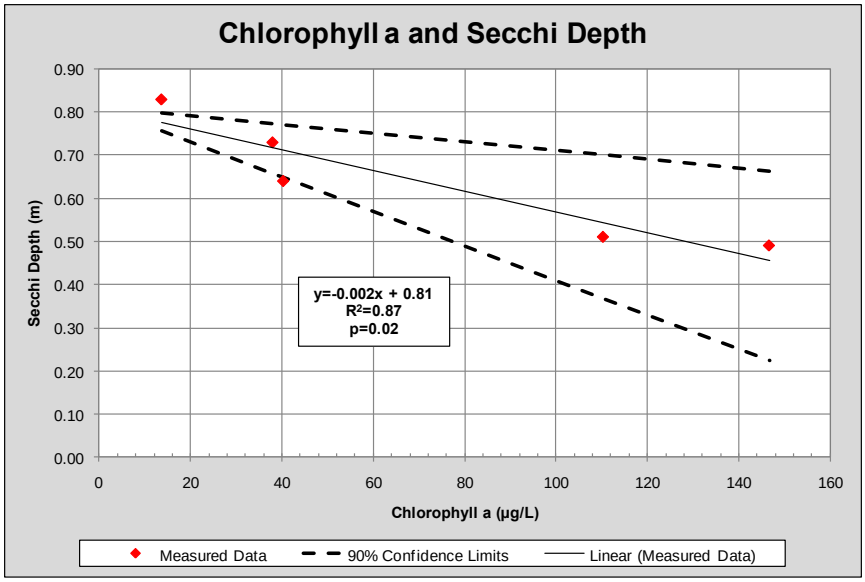
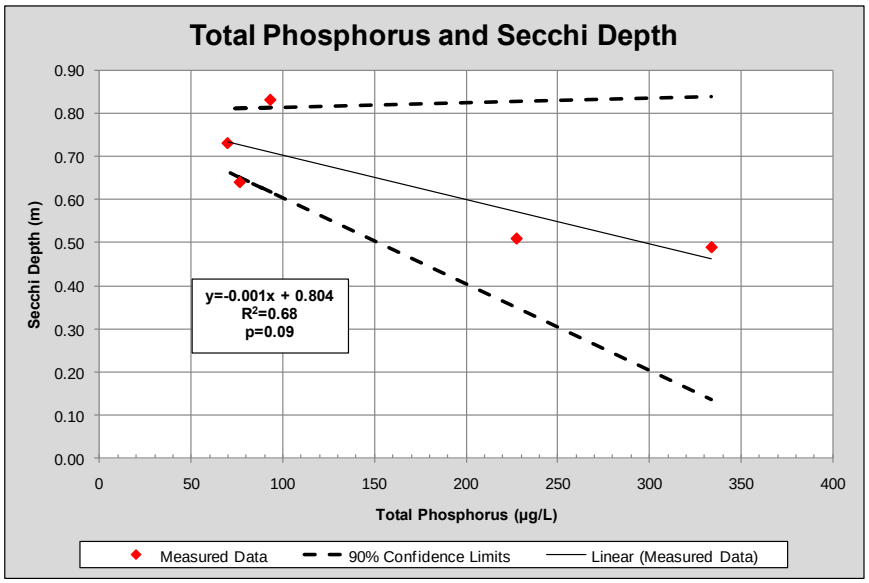


FIGURE 7 – TOTAL PHOSPHORUS AND SECCHI DEPTH RELATIONSHIP IN GILLETTE FISHING LAKE



High nutrient loading during the year can cause a fish kill over the winter, sometimes called a winterkill (MPCA, 2005). Winterkill is a condition that occurs when DO is depleted in the lake over winter, resulting in fish suffocation. It occurs primarily in iced-over shallow lakes (less than 15 feet deep), as is the case for Gillette Fishing Lake. According to WGFD (1976), winterkills occurred nearly every year prior to dredging in 1969. Sedimentation (or siltation) of a lake reduces the amount of water volume available, effectively reducing the amount of DO that is initially present at the start of winter iced-over conditions.

Ice prevents the atmosphere from replenishing the DO in the water. The only source of DO in the winter is the oxygen generated by algae and or plants. Once winter DO levels become anoxic, they will remain low until spring thaw, when the water regains exposure to atmospheric oxygen. Depending on the severity of the event, winterkill conditions may eliminate the game fish species. Non-game fish species or some warm water fish species are able to endure short-term anoxic conditions and may survive in relatively greater numbers than more desirable fish species. Under such conditions, non-game fish species can quickly increase their population densities in subsequent years.

Based on the data collected for the Gillette Fishing Lake TMDL and characteristics of the lake, if the phosphorus loading to Gillette Fishing Lake is reduced, algal production will likely decrease and visibility may improve. If the algal production is reduced, the average summer hypolimnionic DO levels in the lake will likely increase. This increase will improve the water quality in Gillette Fishing Lake, and rest**o**re the warm water fishery and restore the aquatic life other than fish use (appropriate level of algae growth).

9.2 SEDIMENT

Gillette Fishing Lake has been dredged two times since its creation and dredging is needed again. Fisheries use is impacted by the accumulation of excess sediment. This sediment reduces the volume of the lake causing disruption of the dissolved oxygen (DO) cycle. The excess sediment also carries phosphorus and creates nutrient rich environment.

Sediment samples taken at the inlet of the lake have phosphorus associated with it. Data shows that the sediment contains phosphorus. The soil phosphorus concentration utilized was an average of NRCS measured values throughout the watershed (USDA NRCS, 2009). The measurements were taken in several locations throughout Campbell County, therefore displays a more accurate phosphorus concentration than in one location in the watershed. The concentration level was 250 mg/kg.

Channel erosion from Donkey Creek is not a source of sediment according to information from the 205j report. The 205j report discussion is as follows:

> Three reaches on Donkey Creek were measured for channel stability. The findings of the 205j report note that the channels are in good condition and remain stable throughout the entire creek. No incising was present, and channel erosion cannot be blamed for degradation of water quality anywhere along the course of the creek (ICD, 1995).

Therefore, the sources of the accumulated sediment are from upland sources caused by sheet and rill erosion and the sediment delivered to Gillette Fishing Lake is causing a need to dredge the lake.

In order to estimate the accumulated sediment per year into Gillette Fishing Lake, a sediment survey was completed as part of this TMDL. According to the lake sediment survey, an estimated rate of 1,120 tons per year accumulates at the bottom of Gillette Fishing Lake. The sediment from this survey also was analyzed to determine the particle size distribution. The sediment consisted primarily of fine-grained silt and clay sized particles (92 percent silt/clay and 8 percent fine sand). Silt and clay can be considered cohesive sediments (Novotny and Olem, 1994). As shown in a publication by Novonty and Chester (1981), clay and organic matter can effectively adsorb such pollutants as phosphates (Novotny and Olem, 1994).

RUSLE is used to determine sheet and rill erosion. Appendix D explains the application of RUSLE and the factors utilized to determine the erosion contributions based on the land uses (Table 11). The RUSLE estimated sediment yield for the watershed is 1,258 tons per year.

Table 11 displays total area, sediment load, sediment load per acre, and percentage of the sediment load for each land use. The top three land uses that contribute the greatest amount of sediment are construction, urban and Wyoming Big Sage Brush. Table D-13 in appendix D breaks down the subbasins and notes that the highest contributing subbasins included Subbasins 5, 5a, 20, 21, and 17. Subbasins 5a and 21 are directly upstream of Gillette Fishing Lake and are primarily urban land uses. The 205j report also indicated these two subbasins have a greater influence on peak flows and sediment discharge to Gillette Fishing Lake (ICD, 2005).

TABLE 11 – WATERSHED SEDIMENT LOAD SUMMARY

Land Use	Total Area (Acres)	Sediment Load (Tons / Year)	Sediment Load per Acre (tons/year/acre)	Percentage of Sediment Load (%)
Construction	139	280.4	2.1	22.5
Road	492	30.1	0.06	2.4
Rural Residential	3,454	59.4	0.02	4.7
Upland Shrub	6,847	149.0	0.02	11.9
Urban	2,224	152.7	0.07	12.2
Water	369	0.0	0.0	0.0
Wyoming Big Sage Brush	12,192	580.7	0.05	46.3
Total	25717	1252.2	2.32	100

Table 12 shows rangeland land contributing 58 percent of the sediment load and is 74 percent of the watershed. Urban land contributes 42 percent of the sediment load and is 25 percent of the watershed. In Table 11 and 12, Wyoming Big Sage appears to contribute significantly more sediment based on volume alone. This appearance is due to the relative percentage of area the land use type covers in the watershed. Table 11 shows the sediment load per acre. Construction, roads and urban land uses have the greatest sediment load per acre.

The 205j report notes that the urban areas have a greater influence on Gillette Fishing Lake and contribute more sediment than other land uses (ICD, 1995). Subbasins 5, 5a, 17, 20 and 21 contain a large percentage of urban, construction and Wyoming Big Sage Brush land uses. These subbasins are directly connected to Gillette Fishing Lake and have land uses that produce larger amounts of sediment. Table D-15 (Appendix D) lists the sediment delivery ratio (SDR) for all subbasins. The SDRs for subbasins 5, 5a, 17, 20 and 21 are one. An SDR of one delivers all estimated RUSLE sediment yield to the stream and thus to Gillette Fishing Lake. The remaining subbasins have a SDR less than one and these subbasins contain many small impoundments. The lower SDR and small impoundments impede sediment delivery to Gillette Fishing Lake from the upper subbasins.

TABLE 12 – POTENTIAL NONPOINT SOURCES OF SEDIMENT

Land Use	Sediment Load (Tons / Year)	Percentage of Sediment Load (%)	Percentage of Watershed Area (%)
Construction, Road, Rural Residential, and Urban	523	42	25
Wyoming Big Sage Brush and Upland Shrub	730	58	74
Total	1,252	100	100

All of the discussion above leads to the conclusion that sediment accumulation in Gillette Fishing Lake is largely from areas directly or in close proximity to the lake. Urban, construction, road and Wyoming Big Sage Brush land uses (in the lower subbasins) are the primary concern and should be the focus of reductions. Additional reduction in the upper subbasins are needed from the roads and Wyoming Big Sage Brush land uses.

This lake also has had numerous fish kills (WGFD, 1976) (WGFD, 2010). Severe winter kills occurred in 1963, 1992 and 2001 (Nikirk, 2009). Approximately 100 fish died in a fish kill on August 28th, 2009. The dissolved oxygen (DO) measurement throughout the water column during the 2009 fish kill was less than one milligram per liter (mg/L).

High nutrient loading during the year can also cause a fish kill over the winter, sometimes called a winterkill (MPCA, 2005). Winterkill is a condition that occurs when DO is depleted in the lake over winter, resulting in fish suffocation. It occurs primarily in iced-over shallow lakes (less than 15 feet deep), as is the case for Gillette Fishing Lake. According to WGFD (1976), winterkills occurred nearly every year prior to dredging in 1969. Sedimentation (or siltation) of a lake reduces the amount of water volume available, effectively reducing the amount of DO that is initially present at the start of winter iced-over conditions.

The need to dredge and fish kill are the primary indicators that sediment is causing impairments to the aquatic life other than fish and fisheries uses. Phosphorus laden sediment is accumulating in amounts that create an environment that is allowing excessive growth of algae. Excessive algae and shallower water caused by excessive sediment create poor environment for fish and a good environment for algae. These environmental conditions are caused by excessive sediment and are impairing the aquatic life other than fish and fisheries uses.

10.0 EXISTING LOADING

10.1 FLOW

Rating curve development uses staff gage heights and discharge measurements taken by the City's staff at sites T1 and T2. These rating curves allow for additional flow estimates (staff gage flows) from staff gage height measurements. Staff gage flows and flows at USGS Gage Site #06426130, Donkey Creek near Gillette, Wyoming, were compared to determine the average annual flow at sampling sites T1 and T2. Appendix C contains the regression equation from staff gage and USGS flows.

USGS Gage Site #06426130 has 10 complete calendar years of record from 2001 to 2010(USGS, 2001 -2010). Sampling site T1 estimated average annual flow is 666 acre-feet per year. Sampling site T2 estimated average annual flow is 728 acre-feet per year. The estimated outflow is higher than the estimated inflow because the lake receives runoff from the direct watershed, direct precipitation, groundwater infiltration, and due to changes in lake storage.

10.2 SEDIMENT LOAD

10.2.1 POINT SOURCES

All permitted point sources present in the Gillette Fishing Lake watershed are CBM extraction points. At the permitted CBM extraction points, wells are drilled into coal seams and the seams are dewatered to extract the methane. The dischargers then release the groundwater. CBMs are not a source of sediment due to the screening of production water. In addition, each permit states that erosion control measures will be implemented to prevent significant damage or erosion of the receiving water channel at the point of discharge.

The CBM discharge is not a source of sediment in Gillette Fishing Lake. Sediment WLAs are not distributed to any point sources. Reasonable assurance was considered in this analysis and it was determined that reasonable assurance analysis and demonstration are not needed.

10.2.2 NONPOINT SOURCES

10.2.2.1 SEDIMENT SURVEY FOR GILLETTE FISHING LAKE

Sediment load estimates were determined from the amount of accumulated sediment that currently exists within Gillette Fishing Lake (Table 9). A sediment survey for Gillette Fishing Lake occurred from July through August 2009. The original lake water volume and current lake water volume were compared to determine that the accumulated sediment. There is approximately 41,540 cubic yards of accumulated sediment in Gillette Fishing Lake. Using a density of 50 pounds per cubic foot based on sediment particle size analysis of core samples collected in 2009 and the Sedimentation Handbook (Morris and Fan 1997), 41,540 cubic yards converts to 28,040 tons. This is approximately 22 percent of the original lake water volume of approximately 190,150 cubic yards. Over 25 years, there is approximately 1,120 tons per year of sediment on average settling at the bottom of the lake. The accumulated sediment is a portion of the sediment that was delivered to the lake. Additional sediment flowed through the lake and accumulated sediment resuspension accounts for additional sediment that could have flowed out of the lake. Lake trap efficiency determines the total amount of sediment that reaches Gillette Fishing Lake. Brune's Curve (USACE, 1995) is the method this report uses to estimate Gillette Fishing Lake's trap efficiency. Brune's Curve equation is:

$$E = 100 * 0.97 ** 0.19 ** \log(C/I) \text{ or } E = 100\left(0.97^{0.19^{\log C/I}}\right)$$

Where:
E = trap efficiency
C = capacity
I = inflow

Using the lake's average volume of 105 acre-ft, which is the average of the original and current lake volumes of 118 and 92 acre-ft respectively, and the annual average inflow of 666 acre-ft, the lake's trap efficiency is 89 percent (USACE, 1995). The sediment survey conducted by the City determined the amount of trapped sediment in the lake. The trap efficiency method accounts for all of the sediment that enters the lake and either flows through or is resuspended and flows through

due to various natural mechanisms (e.g. biological or wind) and negates the need to explicitly estimate sediment resuspension.

Eighty-nine percent trap efficiency translates to approximately 46,674 cubic yards of sediment reaching the lake from the watershed over the past 25 years. Assuming a density of 50 pounds per cubic foot, the sediment load from the watershed translates to about 1,258 tons per year, as shown in Table 13. Subtracting 1,120 tons per year from 1,258 tons per year yields a resuspension/flow-through rate of about 138 tons per year of sediment.

TABLE 13 – SEDIMENT VALUES BASED ON SEDIMENT SURVEY

Description	Value (cubic yards)	Value (tons)
Measured Sediment Accumulation over 25 years	41,540 cubic yards	28,040 tons
Sediment Reaching Gillette Fishing Lake over 25 years based on Trap Efficiency	46,674 cubic yards	31,505 tons
Annual Sediment Accumulation	N/A	1,120 tons/year
Annual Sediment Reaching Gillette Fishing Lake based on Trap Efficiency	N/A	1,258 tons/year
[1] Numbers have been rounded.		

10.2.2.2 WATERSHED MODELING – SEDIMENT

This TMDL analysis uses RUSLE to estimate potential sediment yield. RUSLE is a model created by USDA to determine rates of soil erosion caused by rainfall and associated overland flow. RUSLE determines soil erosion based on land uses, including rangeland, construction sites, and other lands where rainfall and its associated overland flow cause soil erosion (USDA, 2012).

RUSLE computes sheet and rill erosion from rainfall and the associated runoff for each identified land use. As a revision and update of the widely used Universal Soil Loss Equation (USLE), RUSLE incorporates data from rangeland and other research sites in the United States to significantly improve erosion estimates on untilled lands. This TMDL report uses RUSLE to determine the sediment loading from the watershed due to its applicability to the rangeland areas as well as the urban areas. The factors utilized for the equation were versatile in order to demonstrate the loading coming from the watershed.

The RUSLE equations is:

$$A = R*K*LS*C*P$$

Where:
A = annual soil loss from sheet and rill erosion in tons/acre
R = rainfall erosivity factor
K = soil erodibility factor
LS = slope length and steepness factor
C = cover and management factor
P = support practice factor

Sediment Delivery Ratio (SDR) is used in conjunction with RUSLS to determine the amount of the estimated sediment yield delivered to Gillette Fishing Lake. Appendix D contains the methodology used to calculate each of the RUSLE factors for the watershed, the SDR for each subbasin, and the resulting sediment load values by landuse and subbasin. Table 14 displays the total sediment load calculated by the RUSLE equation and SDR for Gillette Fishing Lake by landuse.

TABLE 14 – WATERSHED SEDIMENT LOAD SUMMARY

Land Use	Sediment Load (Tons / Year)
Construction	280.4
Road	30.1
Rural Residential	59.4
Upland Shrub	149.0
Urban	152.7
Water	0.0
Wyoming Big Sage Brush	580.7
Total	1252.2

Sediment load estimates were determined from the amount of accumulated sediment that currently exists within Gillette Fishing Lake (Table 9). A sediment survey for Gillette Fishing Lake occurred from July through August 2009. The original lake water volume and current lake water volume were compared to determine that the accumulated sediment. There is approximately 41,540 cubic yards of accumulated sediment in Gillette Fishing Lake. Based on the 89 percent trap efficiency of the lake, 46,674 cubic yards of sediment from the watershed reached the lake at an estimated rate of 1,258 tons per year.

Sediment estimation of accumulated sediment calculated by the sediment survey and the estimates of sediment by RUSLE are similar. Sediment measurements are inherently difficult and close approximations of the two methods allow confidence that the sediment accumulation estimates are valid and is approximately the appropriate amount to use for load calculations.

10.3 PHOSPHORUS

10.3.1 POINT SOURCES

All permitted point sources present in the Gillette Fishing Lake watershed are CBM extraction points. Data from the Wyoming Pollutant Discharge Elimination System (WYPDES) program notes that in the watershed, there are 61 outfalls under six permits. Appendix B contains information about these outfalls.

Twenty of the 61 permits are impoundment-type outfalls (Thomas, 2012). Impoundment-type permits virtually eliminate discharge to Donkey Creek because they are hydrologically disconnected. Impoundment-type outfalls do not contribute phosphorus to Gillette Fishing Lake based on hydrologic disconnection.

Forty-one outfalls have direct discharge permits. These sites discharge either into an ephemeral channel or into intermittent streams. For the sites discharging into the ephemeral channels, discharge does not likely reach Gillette Fishing Lake due to the losing nature of streams typical of this area (Thomas, 2012). The sites discharging into the intermittent stream are located upstream of numerous small ponds that act as impoundments and cause all of the direct discharge permits to have similar hydrology to the impoundment-type outfalls (Appendix B). The National Hydrograph Data set and aerial photos were used to evaluate stream types and to determine the existence of small ponds (USGS, 2011).

Therefore, this TMDL does not include any wasteload allocations for TP due to the hydraulic disconnection of discharge water and Gillette Fishing Lake.

10.3.2 Nonpoint Sources

The existing TP concentration measured in the lake is 177 µg/L and is utilized to determine the existing annual TP loading. The existing annual TP load is approximately 920 pounds per year.

To determine loading, four sources were considered: dissolved, particulate, septic, and internal. These sources are nonpoint sources. From these sources, 125 pounds are attributed to internal loading, and 795 pounds of the 920 pound per year are from the remaining sources.

Table 15 displays the dissolved and particulate phosphorus contribution from the watershed. The largest contributors for dissolved phosphorus are urban, road, and rural residential. For particulate phosphorus, construction, Wyoming Big Sage Brush, and urban were the main contributors. In Table 15, Wyoming Big Sage appears to contribute significantly more sediment based on volume alone. This appearance is due to the relative percentage of area the land use type covers in the watershed. Table 11 shows the sediment load per acre. Construction and urban land uses have higher loads per acre. Table 15 shows this same relationship for TP. Construction, roads and urban areas have the greatest per acre TP loads. These land uses in subbasin 5, 5a, 17, 20 and 21 have the greatest TP contributions and have the greatest need for reductions. The remaining subbasins reductions focus should be on construction and road land uses.

TABLE 15 – POTENTIAL NONPOINT SOURCES OF TOTAL PHOSPHORUS

Land Use	Total Area (acres)	Dissolved Phosphorus Load (lbs/year)	Particulate Phosphorus Load (lbs/year)	Total TP (lbs/year)	TP Load per acre (lbs/year/acre)
Construction	139	0.0	140.2	140.2	1.01
Road	492	43.0	15.0	58.0	0.12
Rural Residential	3,454	39.4	29.7	69.1	0.02
Upland Shrub	6,847	0.0	74.5	74.5	0.01
Urban	2,224	85.8	76.3	162.1	0.07
Water	369	0.0	0.0	0	0.00
Wyoming Big Sage Brush	12,192	0.0	290.4	290.4	0.02
Total	25717	168.2	626.1	794.3	

10.3.2.1 LAKE MODELING – PHOSPHORUS

TP modeling for this TMDL analysis used the Iowa Lake Phosphorus Worksheet (the Worksheet). The Worksheet contains several different lake phosphorus equations to analyze the phosphorus concentrations in lakes (Table 16). The Worksheet contains a large set of existing lake modeling equations in one package.

These lake modeling equations use several watershed and lake characteristics to estimate the TP loading required to achieve the target in-lake TP concentration. These factors include lake depth, area, volume, and residence time. The Worksheet checks the basic assumptions used in each of the lake model equations against the characteristics of Gillette Fishing Lake and its watershed. Then the Worksheet identifies whether the lake characteristics match the assumptions. As the inflow rates, residence times, and TP concentrations all change between modeling scenarios, the number of lake models that are applicable also change. In each modeling scenario, all the models in which the model assumptions are considered valid are used. Therefore, when presenting lake modeling results, the number of model results change. A detailed description of each of the lake models is in appendix E.

TABLE 16 – LAKE MODELS UTILIZED

Lake Models
EUTROMOD
Canfield-Bachmann Natural Lake
Canfield-Bachmann Artificial Lake
Walker Reservoir
Reckhow Natural Lake
Reckhow Anoxic Lake
Reckhow Oxic Lake (z/Tw < 50 m/year)
Reckhow Oxic Lake (z/Tw > 50 m/year)
Vollenweider 1982 Combined OECD
Vollenweider 1982 Shallow Lake and Reservoir
Walker Second Order

Section 7.0 discusses the three TP sampling location in Gillette Fishing Lake. The TP samples collected during the growing season (April through August) had an average of 177 µg/L. This average was used in the lake models in the Worksheet. See Table 17 for the results of modeling the average TP concentration for the growing season.

TABLE 17 – LAKE MODELING RESULTS

Lake Model	Average Annual Phosphorus Load (pounds)
Canfield-Bachmann Natural Lake	780
Canfield-Bachmann Artificial Lake	1,360
Walker Reservoir	1,010
Reckhow Anoxic Lake	500
Vollenweider 1982 Combined OECD	760
Vollenweider 1982 Shallow Lake and Reservoir	820
Walker Second Order	1,210
Average	920

10.3.2.2 PHOSPHORUS SOURCE LOADS

The current phosphorus load in Gillette Fishing Lake is 920 pounds per year. This total phosphorus load is made of particulate and dissolved phosphorus.

10.3.2.2.1 PARTICULATE PHOSPHORUS

To determine the particulate phosphorus loading from the watershed, the total sediment delivered to the lake, which was calculated utilizing the RUSLE equation and SDR, was multiplied by a soil phosphorus concentration determined by USDA NRCS (2009) and is displayed in Table 18. The soil phosphorus concentration utilized was an average of NRCS measured values throughout the watershed (USDA NRCS, 2009). The measurements were taken in several locations throughout Campbell County, therefore displays a more accurate phosphorus concentration than in one location in the watershed. The estimated particulate phosphorus loading for the watershed is the following:

Watershed Sediment Loading (1,252 tons/year) * Average soil TP concentration (250 mg/kg) * Unit Conversion * Watershed Particulate TP loading (626 lbs TP / year)

Table 18 shows the particulate phosphorus loading by landuse in the watershed.

TABLE 18 – PARTICULATE PHOSPHORUS LOAD BY LAND USE

Land Use	Particulate Phosphorus Load (lbs/year)
Construction	140.2
Road	15.0
Rural Residential	29.7
Upland Shrub	74.5
Urban	76.3
Water	0.0
Wyoming Big Sage Brush	290.4
Grand Total	626.1

10.3.2.2.2 DISSOLVED PHOSPHORUS

The dissolved phosphorus loading is calculated using the Simple Method. The Simple Method estimates stormwater pollutant loads as the product of mean pollutant concentrations and runoff depths over specified periods of time (usually annual or seasonal) (Schueler, 1987). The Simple Method estimates stormwater runoff pollutant loads for urban areas. The technique requires subwatershed drainage area and impervious cover, stormwater runoff pollutant concentrations, and annual precipitation. With the Simple Method, land uses can be broken into specific areas, such as residential, commercial, industrial, and roadway and calculate annual pollutant loads for each type of land. This method can also utilize more generalized pollutant values for land uses such as new suburban areas, older urban areas, central business districts, and highways. A more detailed description of the Simple Method and the factors used in the method to calculate the dissolved phosphorus watershed loading is located in Appendix D. The final dissolved phosphorus loading values by land use are in Table 19 below.

TABLE 19 – DISSOLVED PHOSPHORUS LOAD BY LAND USE

Land Use	Dissolved Phosphorus Load (lbs/year)
Construction	0.0
Road	43.0
Rural Residential	39.4
Upland Shrub	0.0
Urban	85.8
Water	0.0
Wyoming Big Sage Brush	0.0
Grand Total	168.2

10.3.2.3 SEPTIC

The EPA STEPL On-line Data Access System (EPA STEPL On-line Data Access System, 2012) identified 35 septic systems that in the watershed. The phosphorus loading from those septic systems was calculated using the EPA STEPL model. Appendix D contains detailed information about septic systems. From the number of septic systems, the STEPL model calculated an annual TP load of 1 lb per year of phosphorus from septic systems.

10.3.2.4 INTERNAL LOADING – PHOSPHORUS

The current TP concentration in Gillette Fishing Lake is 177 µg/L. For this TMDL analysis, once all external sources of phosphorus loading were identified, the assumption was made that the remaining load must be originating from internal sources (i.e., lake bottom sediments), either through sediment diagenesis or sediment resuspension. Of the 920 pounds per year of TP loading, the internal loading was determined to be 125 pounds (Table 20). Appendix D contains details of internal phosphorus loading.

TABLE 20 – PHOSPHORUS SOURCES FOR GILLETTE FISHING LAKE

Source	Phosphorus Loading (lbs/year)
Internal Loading	125
Particulate	626
Dissolved	168
Septic	1
Total	920

11.0 TMDL Targets

WDEQ/WQD, CCCD, and the City researched the TP target, which dictates the sediment target, which is appropriate for Gillette Fishing Lake to meet its designated uses.

The two primary pollutants are sediment and Total Phosphorus (TP) and targets are established to reduce these pollutants. The primary goal of these targets is to restore the impaired designated uses: aquatic life other than fish and fisheries. These targets will reduce the TP and sediment from the current loads. Sediment and phosphorus are substances that by themselves and at appropriate levels are not harmful, but in excess, are substances that create undesirable effects to aquatic life other than fish and fisheries uses. Wyoming uses numeric and narrative standards (section 4.0) to evaluate when these substances are affecting designated. The primary sediment and TP targets are established to address the negative effects caused by the excess of these two substances in Gillette Fishing Lake. The secondary targets, chlorophyll a and secchi disk depths, provide guidance and ranges of values to ensure the TP and sediment are at appropriate levels and to instigate further sampling if these secondary targets are out of the appropriate range. If the secondary targets are outside the appropriate range, TP and sediment problems could exist.

11.1 SEDIMENT

The target load capacity of Gillette Fishing Lake for accumulated sediment was determined by the amount of particulate phosphorus that can be assimilated into the lake. The sediment target calculation, based on the assumption that sediment is the main transport mechanism of TP, derives from the TP target. A TP target of 45 µg/L yields an annual TP load to the lake of 160 pounds per year. The average value of TP attached to sediment is 250 mg/kg sediment based on USDA NRCS (2009) soil characterization data. One hundred twenty-six pounds of the 160 pounds TP yearly load is particulate phosphorus. The calculation for sediment load is the mass of the particulate phosphorus load divided by the mass of the mass of the sediment. The result is a calculated sediment load of 252 tons per year of sediment allowed to accumulate in the lake. Table 21 shows that the target loading of particulate phosphorus is 126 pounds per year. Using the average USDA NRCS (2009) value the watershed sediment load derived from TP target is 252 tons of accumulated sediment per year. Assuming a trap efficiency of 89 percent, a sediment loading from the watershed to the lake is 283 tons per year (Table 21). The sediment target uses the TP target to determine the annual load. Therefore, the sediment MOS is implicit.

TABLE 21 – DERIVATION OF TARGET SEDIMENT LOAD

Description	Value
Target Annual TP Load to Gillette Fishing Lake	160 lbs/year
Target Particulate Phosphorus Load	126 lbs/year
Average Measured Concentration of Phosphorus Attached to Sediment	250 mg/kg
Target Amount of Sediment Accumulation in Gillette Fishing Lake	252 tons/year
Target Amount of Sediment Load to Gillette Fishing Lake based on Trap Efficiency	283 tons/year

This target is a 78 percent reduction from its current load. This reduction should ensure that sediment deposition in the bottom of the lake would reduce the need to dredge the sediment as often. The MOS for sediment is accounted for by the MOS for TP.

11.2 TOTAL PHOSPHORUS

Phosphate is the most biologically available form of phosphorus found in natural aquatic systems. Phosphates can exist either in an inorganic form (for example, dissolved orthophosphorus attached to aluminum, calcium, or iron) or in an organic form (for example, particulate or dissolved organic P). While these forms of phosphate undergo continuous transformation, inorganic dissolved phosphate is the most bioavailable form of phosphorus. TP laboratory tests convert all forms of phosphorus to orthophosphate by digestion. Therefore, the TP test encompasses both short-term and long-term phosphorus available for plant uptake, making it a more comprehensive test to use. The use of TP as a target instead of phosphate, for which Gillette Fishing Lake is impaired, will provide better protection for the waterbody by encompassing forms of phosphorus that are currently bioavailable or may become bioavailable.

An appropriate TP target can be set to restore the lake from its current impaired aquatic life other than fish (excessive algae and macrophytes) and poor fishery (low DO due to excessive algae causing fish kills) state, to a system with appropriate levels of algae, macrophytes and fish. The following sections discuss a TP target that is protective of the aquatic life other than fish and fisheries use for Gillette Fishing Lake taking into consideration the physical limitation and current conditions. This target should restore the impaired uses and ensure the protection of the other unimpacted uses.

Review of USEPA's National Strategy for the Development of Regional Nutrient Criteria (USEPA, 1998) occurred initially during the TP target development The strategy presented USEPA's intentions to develop technical guidance manuals for four types of waters (lakes and reservoirs, rivers and streams, estuaries and coastal waters, and wetlands) and produce §304(a) criteria for specific nutrient ecoregions. The ecoregion approach is USEPA's current recommended criteria for TP, total nitrogen (TN), chlorophyll *a*, and Secchi depth for lakes and reservoirs in Aggregate

Nutrient Ecoregion IV (USEPA, 2001). Table 22 displays the reference conditions for the Aggregate Nutrient Ecoregion where Gillette Fishing Lake is located.

TABLE 22 – AGGREGATE NUTRIENT ECOREGION IV REFERENCE CONDITIONS

Nutrient Parameters	Aggregate Nutrient Ecoregion IV Reference Conditions
TP (µg/L)	20
TN (mg/L) (reported)	0.44
Chlorophyll *a* (µg /L) (spectrophotometric method)	2
Secchi Disk Depth (m)	2
Reference: USEPA, 2001	

This standard is relatively low and its basis is on reservoirs and lakes larger than Gillette Fishing Lake. This criteria includes data from many waterbodies that have little resemblance to Gillette Fishing Lake and would create a target value that would be difficult to achieve and scientifically support. Lowering the TP level to 20 µg/L in a shallow, urban lake could create an overly stringent level that is unnecessary for Gillette Fishing Lake to meet its designated uses and might lower the productivity of the lake. This lower productivity level could have the same effect on fish that the ice-over has during winter months. Ice-over and lack of appropriate quantity of dead vegetation for digestion could cause a lack of DO and cause winterkills. The USEPA's Nutrient Ecoregion approach is overly conservative due to the physical differences between Gillette Fishing Lake and lakes used in the strategy's method. Therefore, additional methods were used to determine an appropriate TP target to restore the aquatic life other than fish and fisheries uses.

As an alternative to USEPA's nutrient ecoregion approach, the Trophic State Index (TSI) provides an estimation of the trophic state of a waterbody (USEPA, 2010). TSI is a widely used biomass relationship for lakes (Carlson, 1977; Carlson and Simpson, 1986). TSI values range from zero (ultraoligotrophic) to 100 (hypereutrophic). Secchi depth, chlorophyll a and TP all require separate equations to calculate TSI and are independent of each other. Table 23 displays the three TSI equations: chlorophyll *a* (Chla), TP, and Secchi Depth (SD).

TABLE 23 – CARLSON TROPHIC STATUS INDEX EQUATIONS

TSI Equations
TSI (Chla) = 30.6 + 9.81 ln (Chla)
TSI (TP) = 4.15 + 14.42 ln (TP)
TSI (SD) = 60 – 14.41 ln (SD)
Reference: Carlson, 1977

TSI assesses the trophic state of a lake and determines whether influences such as nutrients or light are limiting algal growth. If the three independent indices have similar values, phosphorus has the potential to limit algal growth. Table 24 displays the trophic classifications and the associated TSI values for US lakes.

TABLE 24 – TROPHIC CLASSIFICATION AND ASSOCIATED TSI VALUES OF U.S. LAKES

Trophic State	TP (µg/l)	Chlorophyll *a* (µg/l)	Secchi Disc Depth (meters)	Lake Use
Oligotrophic TSI < 40	<12	<3	>4	Appropriate for cold water fisheries and water-based recreation. Very high clarity and aesthetically enjoyable.
Mesotrophic 35 < TSI < 50	9-24	2-7	2-6	Appropriate for water-based recreation. Medium clarity.
Eutrophic 50 < TSI < 70	24-96	7-56	0.5-2	Very productive for warm water fisheries. Decrease in aesthetic properties.
Hypereutrophic TSI > 70	>96	>56	<0.5	Summer fish kills possible fisheries, high levels of sedimentation and algae.
References: USEPA, 1988, Nürnberg and Shaw, 1999, and MPCA, 2005				

In a broad generalization, algal productivity ranges from oligotrophic (low algal production) to hypereutrophic (high algal production). Eutrophic lakes (TSI: 50-70) tend to be populated with sunfish, minnows, and other warm water species. Oligotrophic (TSI < 40) cold water lakes tend to be populated with trout, whitefish, and sculpin. Walleye, northern pike, and white suckers and their associates optimally inhabit mesotrophic (TSI: 35-50) environments. Hypereutrophic (TSI > 70) lakes tend to be populated with non-game fish (MPCA, 2005).

The TSI for Gillette Fishing Lake was determined by using data collected at sampling sites L1, L2 and L3. Data at these locations indicate Gillette Fishing Lake resembles a eutrophic lake in the early spring and hypereutrophic lake at the end of the summer. Figure 8 shows the TSI for each sampling data, calculated using all three equations presented in Table 12. Figure 9 displays the mean tropic state index for the five sampling dates that occurred between October 2008 and August 2009, along with lines demarcating the different trophic states.

FIGURE 8 – GILLETTE FISHING LAKE TROPHIC STATE INDEX 2008-2009

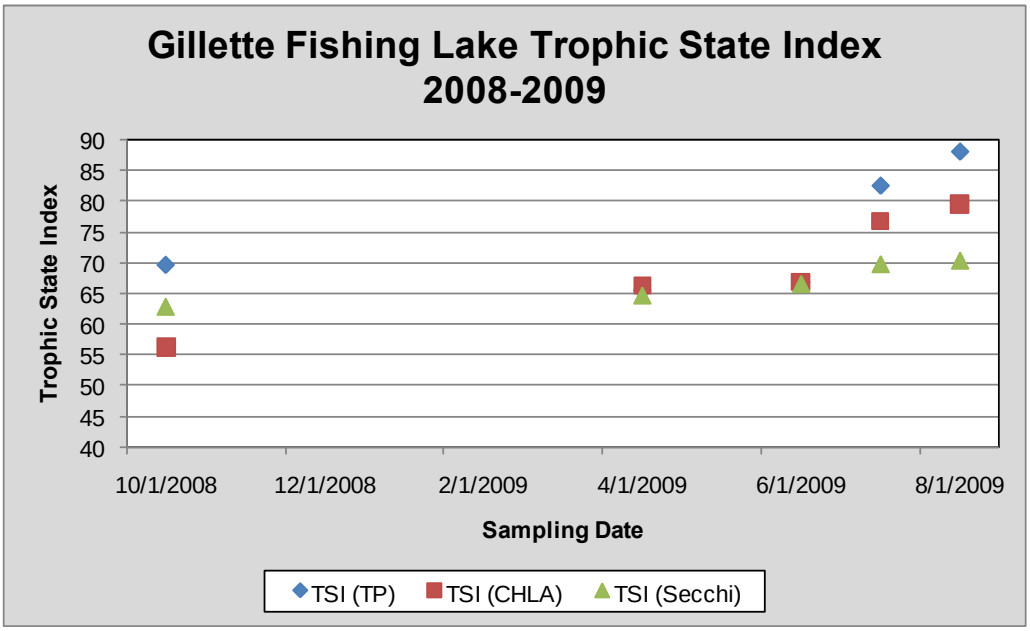
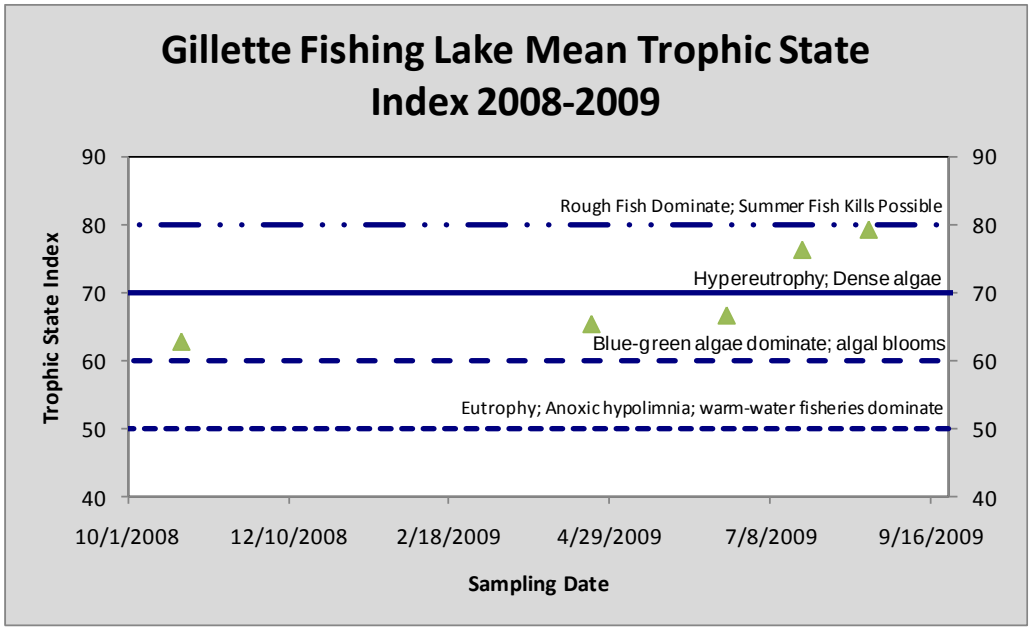


FIGURE 9 – GILLETTE FISHING LAKE MEAN TROPHIC STATE INDEX 2008 AND 2009



Carlson, in 1992, presented the graph below as another way of looking at the TSI data from the various inputs (Figure 10). Apropos to Gillette Fishing Lake, in situations where phosphorus might not be the limiting factor, data would be plotted below the x-axis, as is the case for the July and August 2009 sampling data (Figure 11). In some cases, this can indicate that nitrogen may be the limiting factor; however, for Gillette Fishing Lake, the algae were likely light limited due to the self-shading effects of the algal bloom. Data points lying to the right of the y-axis may indicate that large

formations of cyanobacteria are the main influence on secchi depth as opposed to suspended sediment particles.

FIGURE 10 – ANALYSIS OF TSI DATA

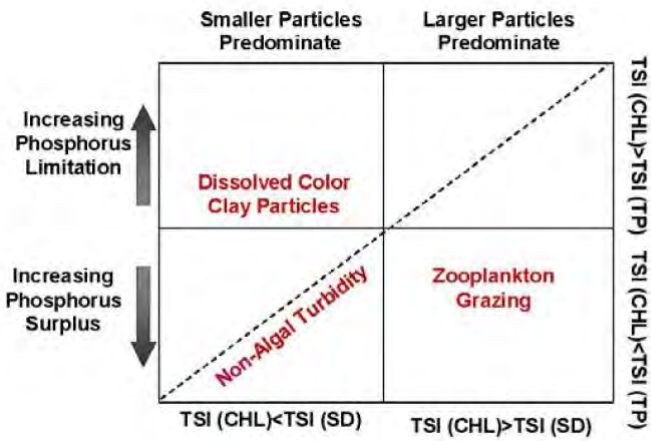
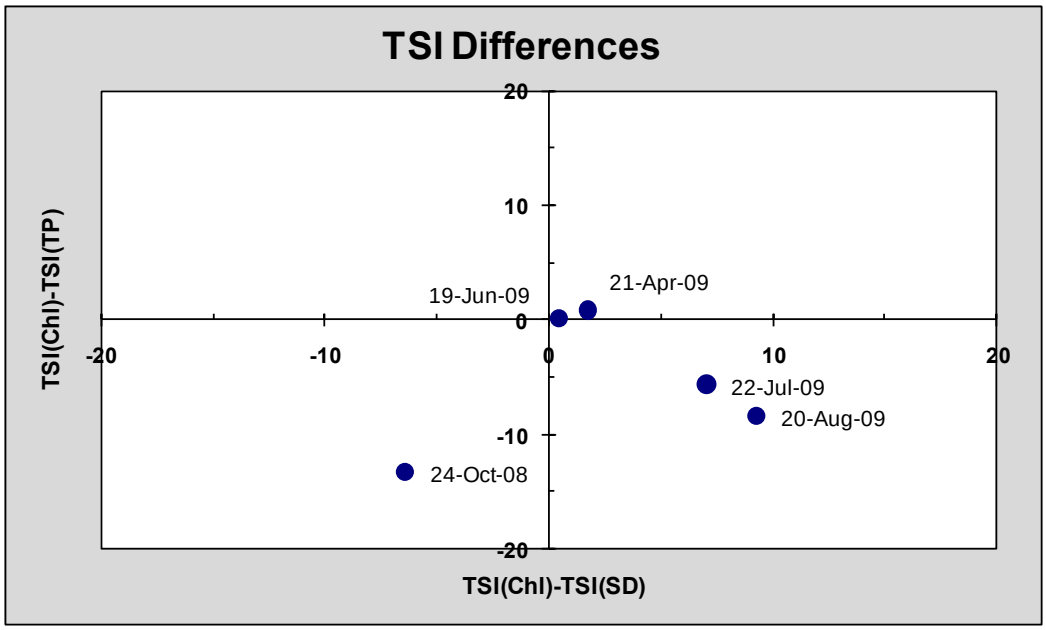
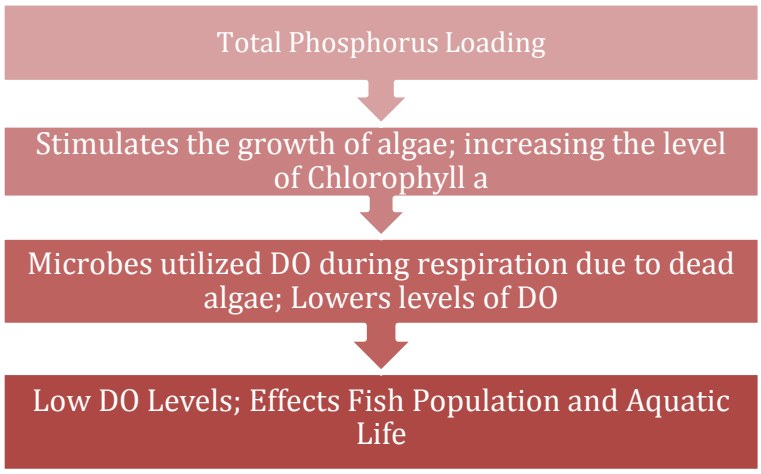


FIGURE 11 – TROPHIC STATE INDEX DIFFERENCES FOR GILLETTE FISHING LAKE



Available data indicate a strong correlation between the levels of chlorophyll *a* and TP within Gillette Fishing Lake. These data, coupled with the understanding that most inland lakes are phosphorus limited, suggest that TP is the nutrient that is directly related to excess algal production in Gillette Fishing Lake. The level of chlorophyll *a* and TP also shows a TSI of hypereutrophic conditions in Gillette Fishing Lake in late summer. Figure 12 displays in general terms the relationship of nutrient loading impairments occurring within Gillette Fishing Lake.

FIGURE 12 – RELATIONSHIP OF NUTRIENT LOADING AND USE IMPAIRMENTS



The goal of selecting a TP target is to choose a level that would reduce algae blooms and stabilize the DO levels. An appropriate TP target would reduce chlorophyll *a* levels and protect the aquatic life other than fish and fisheries uses.

The TP target selected is at a level that would reduce algae blooms, thus reducing the potential for unwanted negative visual and biological effects of algae. Although DEQ does not have standards to assess the scenic value use, the TP target and associated sediment target is set to ensure the lake will meet all water quality standards including scenic value use. Reducing algae will improve clarity in the lake.

Figures 5, 6 and 7 display a high correlation between TP, chlorophyll a, and secchi disk depths. This relationship provides scientific evidence that by reducing phosphorus laden sediment the production of algae would decrease and DO would increase. A decrease in algae available for microbial respiration will increase the potential for fish survival and would improve the water quality in the lake.

By using the relationship between chlorophyll *a* and TP in Gillette Fishing Lake, an appropriate trophic state for Gillette Fishing Lake is a TSI of 60. TSI of 60 for Gillette Fishing Lake translates to a TP level of 50 µg/L using the TP equation in table 23.

In discussions with WGFD (Nikirk, 2009), the desired warm water fishery species within Gillette Fishing Lake would be the largemouth bass and black crappie. These species are present in the drainage area, which includes Keyhole Reservoir. MPCA (2005) has previously researched fishery populations and TP concentrations. The information within the MPCA (2005) document also supports the selection of a TP level of 50 µg/L, and this level translates to a TSI value of 60 for Gillette Fishing Lake based on the following evidence:

- Schupp (MPCA, 2005) noted some distinct relationships among TSI and the present relative abundance and size of several fish species. Schupp observed that black crappies, an example of a warm water species, tended to increase in abundance as TSI increased from 55 (approximately 35 µg/L TP) to about 65 to 70 (approximately 70 µg/L TP).

- Moyle (MPCA, 2005) noted that most central Minnesota lakes had a mean TP level of 58 µg/L and were historically bass and panfish lakes. Schupp and Wilson (MPCA, 2005) discussed the high water quality and relative abundance and presence of various fish (as represented by TSI). Largemouth bass, a sight-feeder piscivores, is noted earlier as being most abundant at a TSI of 40.
- Moyle (1956) documents declines in the number of fish species, such as walleye, northern pike and largemouth bass, with increases above 70 TSI.

Determining the TP target was based on the need to restore the aquatic life other than fish and fisheries uses. The data suggests that Gillette Fishing Lake tends to be more hypereutrophic in fall due to the excessive algae production. Excessive algae production and die off and decay is reducing the quality of the fisheries use. Reducing TP to 50 µg/L should reduce the excessive algae growth based on the relationship established in figures 5, 6 and 7. In addition to this relationship, a TP of 50 µg/L translates to a TSI(TP) of 60 using the equation in table 23. A TSI of 60 is in the middle of the range for a eutrophic lake (Table 13). Using equations in table 12 and a TSI of 60 produces a chlorophyll a value of approximately 21µg/L and is within the eutrophic range (Table 24). The chlorophyll a value using the equation for the trend line in figure 5 is approximately 20µg/L. Using a weight of evidence approach, the TP target of 50µg/L is appropriate for Gillette Fishing Lake.

The TP level that allows Gillette Fishing Lake to meet its designated uses is 50 µg/L. Due to variability and uncertainties of data, this TMDL uses an explicit MOS. The MOS is a 10 percent reduction of the appropriate 50 µg/L TP level. Therefore, the TP target for this TMDL is 45 µg /L, which will be protective of the designated uses of Gillette Fishing Lake.

The TP target reduces the current growing season average from 177 µg/L to 45 µg/L. This TP target will decrease algae production, create appropriate DO levels, and restore the aquatic life other than fish and fisheries uses. A TP target of 45 µg/L is associated with eutrophic condition more suitable for warm water fisheries. The target TP range would keep the lake trophic state from reaching hypereutrophic levels, which would improve water clarity and DO levels, and reduce the occurrence of algal blooms and fish kills. A TP target to 45µg/L will restore the aquatic life other than fish and fisheries uses and will continue to protect the other uses. Finally, the 45 µg/L TP target may need revision when WDEQ establishes numeric nutrient criteria or other information indicates that this target is inaccurate.

The TP target of 45 µg/L was input into the Worksheet. The model predicts an average TP load of 160 pounds, as shown in Table 25.

TABLE 25 – LAKE MODELED UTILIZING TARGET OF 45 µg/L OF TOTAL PHOSPHORUS

Lake Model – Using 45 µg/L	Average Annual Phosphorus Load (pounds)
EUTROMOD	120
Canfield-Bachmann Natural Lake	150
Canfield-Bachmann Artificial Lake	180
Walker Reservoir	130
Reckhow Natural Lake	250
Reckhow Anoxic Lake	130
Vollenweider 1982 Combined OECD	140
Vollenweider 1982 Shallow Lake and Reservoir	170
Walker Second Order	140
Average	160

The target TP load of 160 pounds per year is broken down into particulate phosphorus and dissolved phosphorus. Table 26 shows the sources and target loads of TP to Gillette Fishing Lake. The percentage of particulate phosphorus of the total nonpoint source load is approximately 79 percent.

TABLE 26 – PHOSPHORUS LOADING

Source	TP Loading (lbs/year)
Internal	0
Particulate	126
Dissolved	34
Septic	0
Total	160

11.3 SECONDARY TARGETS

The sediment and TP targets are based on the lake having an overabundance of phosphorous, carried into the lake from the direct watershed and bioturbation of sediment in the bottom. Elevated phosphorous allows excessive growth of algae. Excessive growth of algae can elevate chlorophyll a levels, decrease visibility and consume DO during decomposition. Data from the lake confirms that TP, chlorophyll a and secchi disk depths have a correlating trend. As TP increases, chlorophyll a increases (Figure 5) and secchi disk depth visibility decreases (Figure 7). These trends have a high correlation, but due to the lack of long-term data, the use of these indicators as primary targets could be misleading. Therefore, chlorophyll a and secchi disk depths are only secondary targets that help evaluate TP and sediment trends.

Appropriate levels for chlorophyll range between 10 and 25µg/L. This range was determined using the trend line in figure 5 and is consistent with eutrophic conditions in table 24.

Appropriate depths for the secchi disk range between 0.81 and 0.70 meters. This range was determined using the trend line in figure 7 and is consistent with depths associated with eutrophic lakes in table 24.

The two secondary targets will not only help ensure the aquatic life other than fish and fisheries uses are protected, but these targets help evaluate impacts to other uses such scenic value, agriculture, industry and wildlife. The primary and secondary targets provide values to evaluate the need to reduce undesirable aquatic life (algae), and sediment (deposited and suspended). These targets are based on data collected for this project, analysis of these data, and are consistent with other literature values.

12.0 POLLUTANT ALLOCATION

A TMDL allocates pollutant loads to all sources, including point sources (WLA) and nonpoint (LA). In addition, a MOS is included to account for the uncertainty inherent in the analysis and to ensure that designated uses are protected in the future. The TMDL equation is:

$$TMDL = WLAs + LAs + MOS$$

The MOS is a required part of the TMDL development process. The CFR require that a TMDL include a margin of safety to account for any lack of knowledge concerning the relationship between load and wasteload allocations and water quality (CWA §303(d) (1) (C), 40 CFR §130.7(c) (1)). U.S. EPA's 1999 Protocol for Developing Nutrient TMDLs explains that the margin of safety accounts for uncertainty in the relationship between pollutant loads and receiving water quality. The margin of safety can be implicit through analytical assumptions or explicit by reserving a portion of loading capacity. If the margin of safety is explicit, the loading set aside for the margin of safety must be identified.

Gillette Fishing Lake TMDL analysis was developed using yearly sediment accumulation rates in the lake. Sediment load estimates were completed using RUSLE and sediment delivery ratio (SDR), which estimates annual sediment delivery. Average growing season samples were used to determine the TP conditions of Gillette Fishing Lake. The appropriate load estimate for the lake is based on concentrations of TP during this time. Methods and models used to determine loads from different sources and different forms of phosphorus created annual outputs. Based on the available data and models used it would be appropriate to divide the annual loads by 365 (days in a year) to get an average daily loading rate from the allowable annual loads. The average daily rates are difficult to measure, especially for sediment and resulting measured values could vary based on seasonality of flow.

The estimated TP concentration of 45µg/L could be considered an average growing season concentration limit and could be used to determine if both TP and sediment are below amounts that would be protective of the water quality standards. It must be understood that the growing season average must be under 45µg/L and there could be TP measurements that are higher or lower due to the varying nature of the TP transport mechanism (sediment) and internal loading.

12.1 SEDIMENT

The annual sediment load for Gillette Fishing Lake is the sediment accumulation load of 252 tons per year. The TMDL for sediment is 0.69 tons per day (Table 27).

TABLE 27 – SEDIMENT TMDL FOR GILLETTE FISHING LAKE

	Existing Annual Load	Target Annual Load	Daily Load	Percent Reductions
Wasteload Allocation (WLA)	0	0	0	0
Load Allocation (LA)	1,120 tons per year of accumulated sediment within the lake 1,258 tons per year of sediment delivered to Gillette Fishing Lake	252 tons per year of accumulated sediment within the lake 283 tons per year of sediment delivered to Gillette Fishing Lake	0.69 tons per day of accumulated sediment within the lake	78

12.1.1 WASTELOAD ALLOCATION

Sediment contributions are not occurring from point sources. The point sources within the watershed are CBM permits that extract groundwater to harvest methane. All permits are either direct discharge permits or impoundment-type permits. Hydrologic disconnection of the discharges serve as evidence that point sources are not sources of sediment. Each permit contains a clause that states that erosion control measures will be implemented to prevent significant damage to or erosion of the receiving water channel at the point of discharge. Therefore, a WLA in not applicable for Gillette Fishing Lake. Reasonable assurance discussion and demonstration is not needed due to the lack of point source contributions.

12.1.2 LOAD ALLOCATION

Nonpoint sources of sediment for Gillette Fishing Lake are delivered by sheet and rill erosion from the direct and adjacent subbasins and in lesser amounts from the remaining subbasins. The goal is to reduce the excess sediment flowing in from the watershed to reduce sediment accumulation in the lake bottom and to reduce the frequency of dredging. The annual sediment load allocation is 252 tons per year. The TMDL LA for sediment is 0.69 tons per day.

12.1.3 MARGIN OF SAFETY

The MOS for sediment is implicit. The sediment target was set using the TP target that contains a 10 percent MOS. An additional MOS for sediment is implicitly accounted for by assuming that the 1984 dredging removed all of the accumulated sediment.

12.2 PHOSPHORUS

The annual phosphorus load for Gillette Fishing Lake equals the load of 160 pounds of TP per year, accounting for the 10 percent MOS (Table 28). The TMDL for TP is 0.44 pounds per day.

TABLE 28 – TP TMDL FOR GILLETTE FISHING LAKE

	Existing Annual Load (lbs/year)	Target Annual Load (lbs/year)	Daily Load (lbs/day)	Percent Reductions (%)
Wasteload Allocation (WLA)	0	0	0	0
Load Allocation (LA)	920	160	0.44	83

12.2.1 WASTELOAD ALLOCATION

The point sources within the watershed are CBM extraction sites. Discharge water is typically free of phosphorus. Extracted groundwater does not reach Gillette Fishing Lake due to the releases being hydrologically disconnected. Reasonable assurance discussion and demonstration is not needed due to the lack of point source contributions.

12.2.2 LOAD ALLOCATION

Nonpoint sources of TP come primarily from the direct runoff to the lake and the Gillette Fishing Lake watershed. The desired target is to reduce the TP flowing in from the entire and direct watershed. The load allocation is 160 pounds of TP per year. The TMDL LA for TP is 0.44 pounds per day.

12.2.3 MARGIN OF SAFETY

The MOS for Gillette Fishing Lake is 10 percent of the 50 µg/L of TP appropriate for the lake. Therefore, the target with the MOS applied for TP is 45 µg/L. In addition to the explicit MOS applied to the TP target, an over estimate of sediment accumulation was used in the assumption that all sediment was removed in the 1984 dredging.

13.0 MONITORING

Monitoring recommendations include continuing lake sampling to better establishing baseline conditions for the lake and to monitor the effectiveness of the targets established. Monitor also contributes to determining progress toward attainment of the TMDL and determining designated use support in Gillette Fishing Lake. Monitoring recommendations include, but are not limited to the following:

- Conduct seasonal (spring, summer, and fall) monitoring of phosphorus, chlorophyll a, and secchi disk depths at the three sampling locations in Gillette Fishing Lake.

- Take monthly (April through November) measurements of flow and phosphorus at the inlet and outlet to Gillette Fishing Lake.
- Conduct a sediment survey of the accumulated sediment at the bottom of Gillette Fishing Lake every 5 years.
- WGFD should continue to stock and monitor the fish populations within Gillette Fishing Lake.

14.0 PUBLIC PARTICIPATION

Public participation for the Gillette Fishing Lake TMDL included stakeholder meetings, public meetings and a public comment period. A public meeting to discuss the project occurred on November 20, 2008. A kick-off meeting was held on November 21, 2008, for the following stakeholders: CCCD, the City, and WDEQ. Conference calls between WDEQ, the City and HDR occurred on March 8th 2010 and June 2nd, 2010.

Public comments were solicited from April 9th, 2012 to May 8th. Announcement of this public comment period was made in the Gillette News Record. One comment was received. The comment was a statement of support. This comment had nothing to address.

15.0 IMPLEMENTATION PLAN

The following goals and objectives are designed to meet the targets of this TMDL. WDEQ/WQD, CCCD, and the City should continue efforts of implementing BMPs and updating the Gillette Fishing Lake Water Quality Improvement Plan. Through this plan, goals and objectives will be determined to address implementation of BMPs to improve the water quality of Gillette Fishing Lake.

The goals and objectives address the following watershed concerns: sediment delivery from urban, construction, road and Wyoming Big Sage Brush land uses, stakeholder coordination, education, information dissemination, and water quality monitoring. Some of these items are from the Gillette Fishing Lake Water Quality Improvement Plan, and additional the additional items will help to reduce the sediment and phosphorus loading:

- Landscape Management
  - Create vegetated buffers along Donkey Creek's tributaries, Donkey Creek, and Gillette Fishing Lake. Vegetated buffers can capture stormwater runoff and provide a filter for nutrients and sediment.
  - Install a bank stabilization system around Gillette Fishing Lake to prevent sediment erosion
- Control of Urban Runoff and Sediment Delivery
  - Continue street sweeping program on roadways directly adjacent to Gillette Fishing Lake and increasing the removal of aggregate particles applied to the city streets during times of winter and icy road conditions – The program should continue to sweep the streets as well as the parking lots that surround Gillette Fishing Lake

- Continue to install and maintain hydrodynamic devices to appropriate stormwater drainages in the watershed
- Establish a stormwater management program that will include the following tasks:
  - Update the stormwater infrastructure inventory
  - Develop an inspection and maintenance program
  - Develop comprehensive stormwater design and construction criteria and standards
  - Develop erosion and sediment management policy and criteria
  - Develop a BMP inventory
  - Develop a proactive Erosion and Sediment Control and BMP inspection program
- Continue to construct drainage improvements for specific subdivisions within the watershed.
- Determine an appropriate dredging frequency and dredge Gillette Fishing Lake accordingly
- Construct sedimentation pond(s) at the Donkey Creek inlet to capture sediment

- Agriculture Phosphorus Management
  - Discourage excessive fertilizer application to cropland and pastures
  - Encourage correct sewage management practices for cattle operations, such as fencing off cattle from the creek and provide off site watering locations
- Stakeholder Coordination
  - Stakeholders BMPs planning and implementation
    - Determine goals and objectives for restoration efforts. Specific goals and objectives should be assigned to each Stakeholder
    - Develop and implement information and education campaigns throughout the watershed
    - Implement BMPs within the City's jurisdiction and monitoring of the effectiveness of the BMPs
    - Review TMDL every five years, when conditions have changed, or when the State has developed nutrient criteria
- Public Participation
  - Continue the following public participation items:
    - Enviroscape – Develop a model to display information about nonpoint source pollution and control and continue to present it to classrooms and at public events
    - Storm Stencils – Continue to encourage groups, such as boy and girl scouts, to affix storm drains stencils on storm drains within the city
    - Brochures – Prepare and distribute brochures regarding nonpoint source pollution throughout the community.

- Educate and encourage people within the watershed to use fertilizers sparingly on lawns and gardens, plant vegetation in bare areas, encourage neighborhoods to do routine clean ups and dispose of household cleaner chemicals correctly

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TABLE A-1 – BLANK SAMPLES COLLECTED AT SAMPLING SITES L1, L2, AND L3

	24-Oct-08	21-Apr-09	19-Jun-09	22-Jul-09	20-Aug-09
Parameter	**Blank of L1**	**Blank of L2**	**Blank of L3**	**Blank of L1**	**Blank of L2**
Chlorophyll-*a* (mg/m^3)	1.00	1.2	2	1.8	1.5
Nitrate (mg/L)	ND	ND	ND	ND	ND
Nitrite (mg/L)	ND	ND	ND	ND	ND
Nitrate+Nitrite (mg/L)	ND	ND	ND	ND	ND
TSS (mg/L)	ND	ND	ND	ND	ND
Orthophosphate as P (mg/L)	ND	ND	ND	ND	ND
Total Phosphorus as P (mg/L)	ND	ND	ND	ND	ND
Notes: ND=Nondetect					

TABLE A-2 – DUPLICATE SAMPLES COLLECTED AT SAMPLING SITES L1, L2, AND L3

	24-Oct-08		21-Apr-09		19-Jun-09		22-Jul-09		20-Aug-09	
Parameter	**Duplicate**	**L1**	**Duplicate**	**L2**	**Duplicate**	**L3**	**Duplicate**	**L1**	**Duplicate**	**L2**
Total Depth (m)	2.00	2.00	2.00	2.00	2.7	2.7	1.45	1.45	2.2	2.2
Temperature (°C)										
Surface	6.04	6.04	10.60	10.57	20.9	20	24.97	24.27	18.25	18.24
0.50 m	6.05	6.05	10.59	10.55	19.49	19.41	21.84	22.18	18.23	18.23
1.00 m	6.05	6.05	10.55	10.45	18.46	18.93	21.05	21.14	18.21	18.22
1.50 m			10.24	10.32	17.76	18.12			18.19	18.19
2.0 m					17.15	17.42				
2.5 m					15.95	16.04				
DO (mg/L)										
Surface	8.27	8.27	10.92	11.05	10.19	10.73	16.64	16.3	8.15	8.12
0.50 m	8.24	8.24	10.95	10.93	10.87	10.74	13.79	15.34	8.2	8.22
1.00 m	7.95	7.95	10.93	10.94	10.57	10.31	4.09	6.34	8.03	8.04
1.50 m			10.99	10.98	6.44	7.39			7.92	7.9
2.0 m					2.49	2.94				
2.5 m					0.15	0.16				
pH										
Surface	7.99	7.99	8.12	8.13	8.52	8.64	8.86	8.89	8.54	8.53
0.50 m	7.97	7.97	8.12	8.13	8.56	8.68	8.58	8.67	8.58	8.58
1.00 m	7.94	7.94	8.12	8.13	8.54	8.7	8.08	8.09	8.62	8.63
1.50 m			8.12	8.12	8.27	8.56			8.64	8.64
2.0 m					8.05	8.26				
2.5 m					7.92	8.03				
pH Integrated	7.89	7.89	8.18	8.18	8.53	8.62	8.84	8.84	8.68	8.68
Turbidity (NTU)	5.58	5.58	7.68	8.39	11.6	13	15.2	13.6	12.8	16.1
Secchi Depth (m)	1.00	1.00	0.70	0.72	0.56	0.58	0.46	0.43	0.43	0.43
Chlorophyll-*a* (mg/m^3)	15.00	14.00	36.00	47.00	52	42	220	230	290	200
Nitrate (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Nitrite (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Nitrate+Nitrite (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TSS (mg/L)	9.00	9.00	10.00	12.00	14	14	38	42	39	28
Orthophosphate as P (mg/L)	0.02	0.02	0.02	0.02	0.03	0.03	0.051	0.053	0.165	0.164
Total Phosphorus as P (mg/L)	0.08	0.07	0.07	0.07	0.07	0.07	0.327	0.297	0.342	0.407

Notes: ND= Nondetect

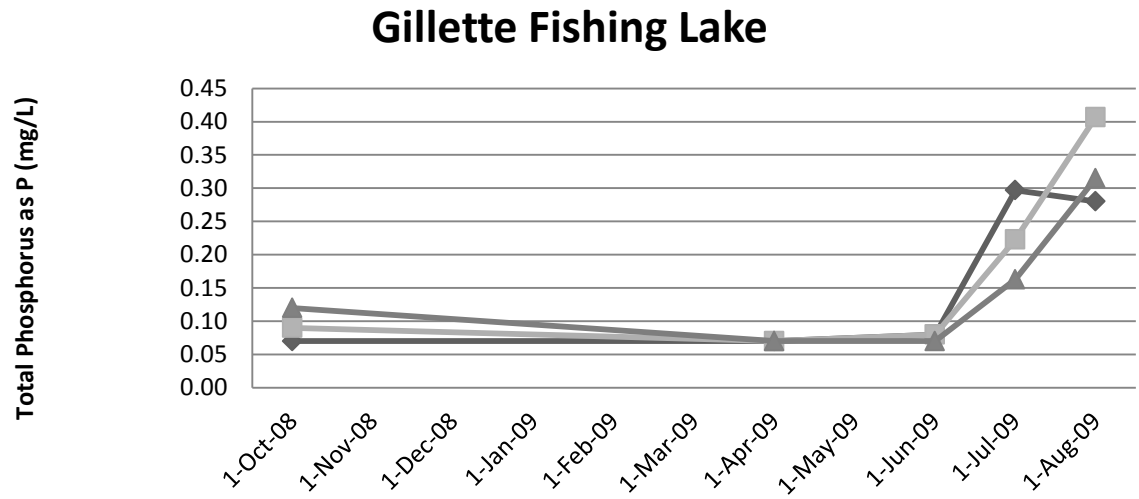
TABLE A-3 – BLANK SAMPLES FOR SAMPLING SITES T1 AND T2

	23-Oct-09	8-Jun-09
Parameter	**Blank of T2**	**Blank of T1**
Nitrate (mg/L)	ND	ND
Nitrite (mg/L)	ND	ND
Nitrate+Nitrite (mg/L)	ND	ND
TSS (mg/L)	ND	ND
Orthophosphate as P (mg/L)	ND	ND
Total Phosphorus as P (mg/L)	0.01	ND
Notes: ND=Nondetect		

TABLE A-4 – DUPLICATE SAMPLES FOR SAMPLING SITES T1 AND T2

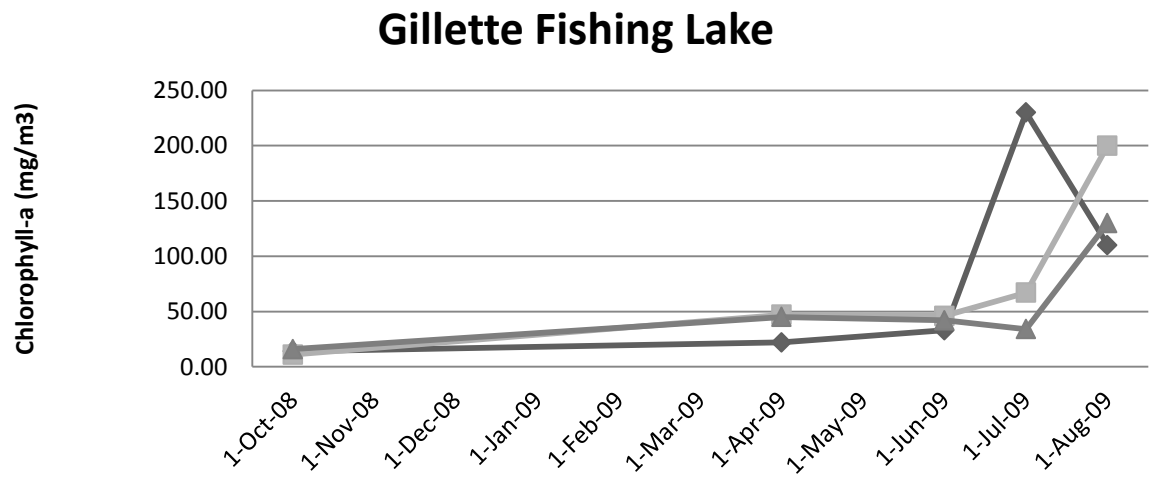
	23-Oct-09		8-Jun-09	
Parameter	**Duplicate**	**T2**	**Duplicate**	**T1**
Staff Gauge (ft)	0.96	0.96	0.6	0.6
Temperature (°C)	6.31	6.31	11.41	11.42
DO (mg/L)	10.63	10.63	4.25	4.29
pH	8.14	8.14	8.13	8.09
Turbidity (NTU)	5.85	5.85	6.65	5.92
Nitrate (mg/L)	ND	ND	0.1	0.10
Nitrite (mg/L)	ND	ND	ND	ND
Nitrate+Nitrite (mg/L)	ND	ND	0.1	0.10
TSS (mg/L)	6	6	ND	ND
Orthophosphate as P (mg/L)	0.01	0.01	0.11	0.12
TP as P (mg/L)	0.07	0.06	0.17	0.17
Notes: ND=Nondetect				

FIGURE A-1 – TOTAL PHOSPHORUS CONCENTRATIONS WITHIN GILLETTE FISHING LAKE



	24-Oct-08	21-Apr-09	19-Jun-09	22-Jul-09	20-Aug-09
Sampling Site L1	0.07	0.07	0.08	0.30	0.28
Sampling Site L2	0.09	0.07	0.08	0.22	0.41
Sampling Site L3	0.12	0.07	0.07	0.16	0.32

Figure A-2 – Chlorophyll-a Concentrations within Gillette Fishing Lake



	24-Oct-08	21-Apr-09	19-Jun-09	22-Jul-09	20-Aug-09
Sampling Site L1	14.00	22.00	33.00	230.00	110.00
Sampling Site L2	11.00	47.00	46.00	67.00	200.00
Sampling Site L3	16.00	45.00	42.00	34.00	130.00

FIGURE A-3 – DISSOLVED OXYGEN LEVELS WITHIN GILLETTE FISHING LAKE

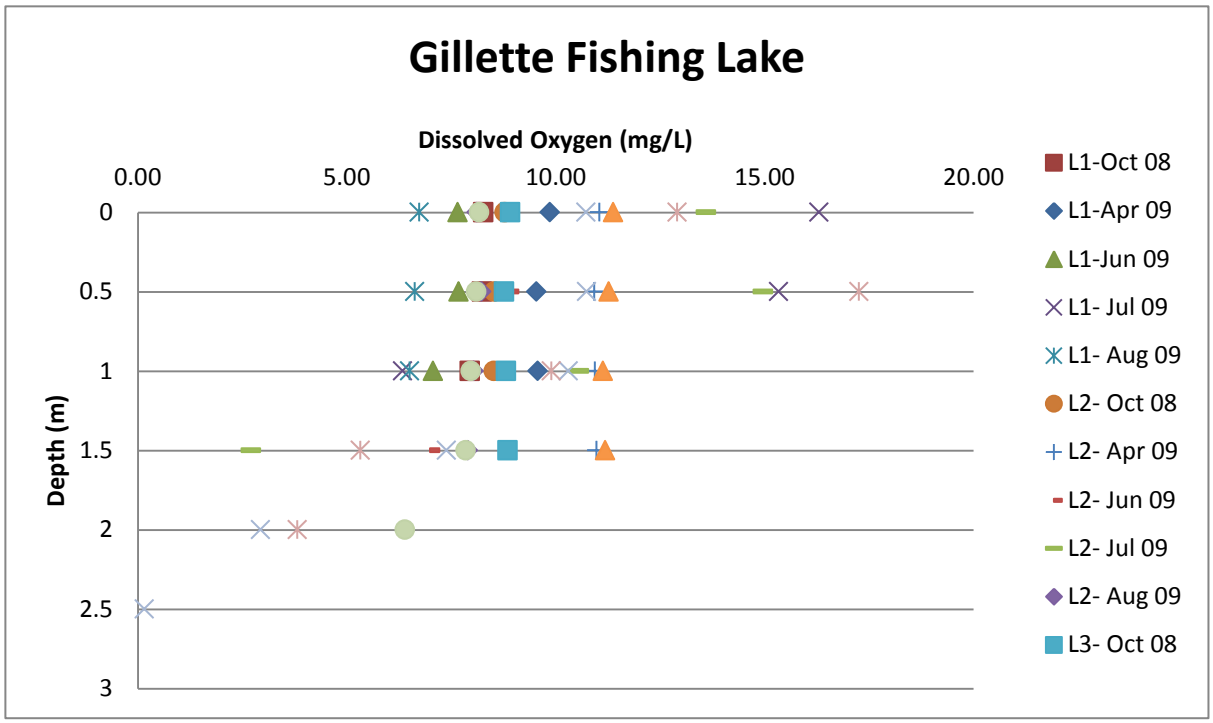


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FIGURE B-1 – POINT SOURCE IN GILLETTE FISHING LAKE WATERSHED

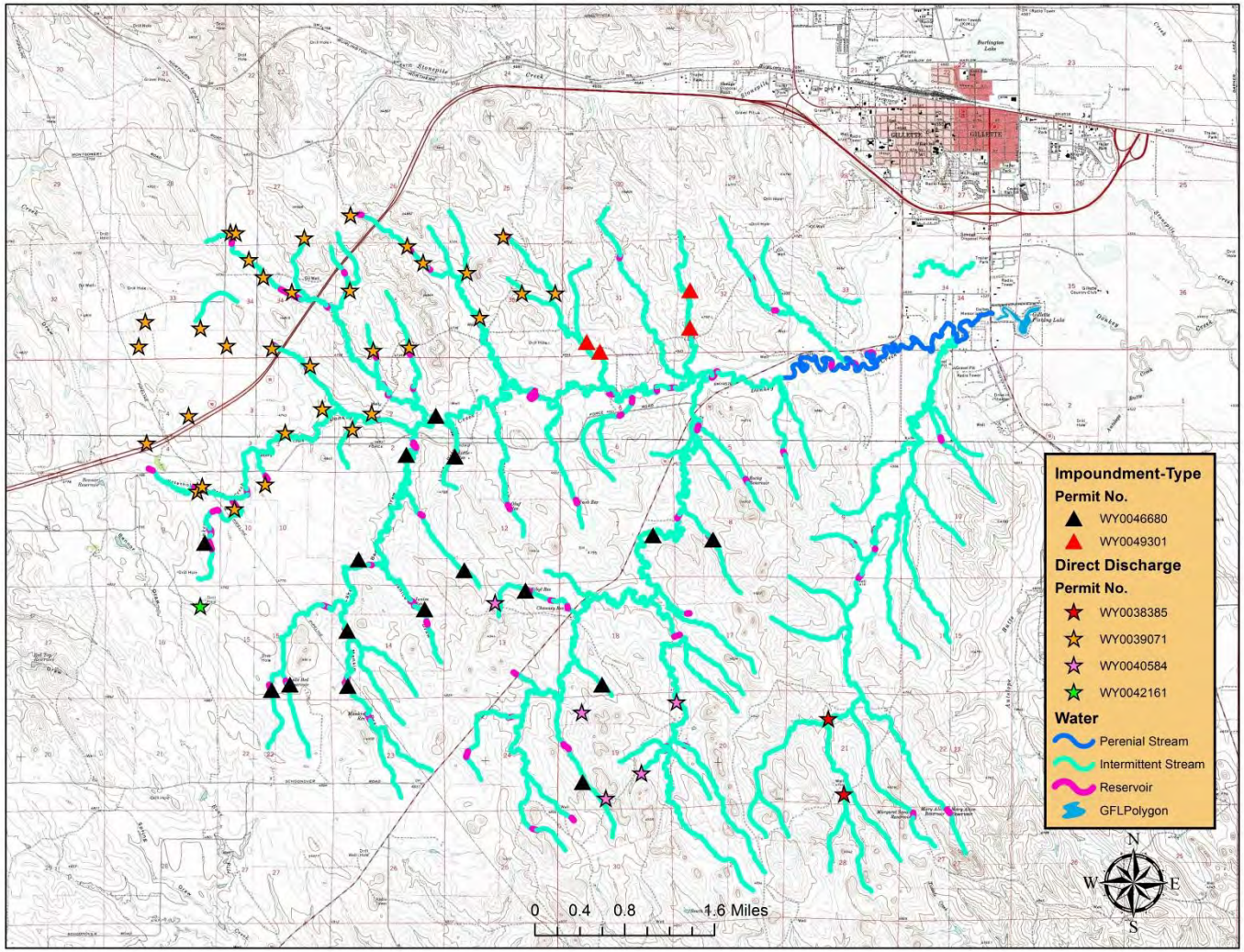

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Figure C-6 – Linear Regression Method for Estimating Flows at Inlet for Low Flows
Figure C-7 – Linear Regression Method for Estimating Flows at Inlet for Low Flows
Figure C-8 – Linear Regression Method for Estimating Flows at Inlet for High Flows

1. FLOW MEASUREMENTS

This appendix outlines the information and calculations utilized to estimate the discharge at the inlet and outlet of Gillette Fishing Lake. The following discussion outlines the information utilized.

Table C-1 shows the mean annual (water year) discharge measured at the USGS gage station, USGS 06426130 DONKEY CREEK NEAR GILLETTE, WY, on Donkey Creek near Gillette, WY, and the associated annual volumes. The location of this station is downstream of Gillette Fishing Lake.

TABLE C-1 – MEAN ANNUAL FLOW AND VOLUME, WATER YEAR AT USGS 06426130 DONKEY CREEK NEAR GILLETTE, WY

Water Year	Discharge, (cfs)	Volume (Acre-ft)
2001	2.67	1,933
2002	0.504	365
2003	1.11	804
2004	0.699	506
2005	1.16	840
2006	0.751	544
2007	3.31	2,396
2008	2.86	2,071
2009	2.75	1,991
2010	2.17	1,571

TABLE C-2 – MEAN ANNUAL FLOW AND VOLUME, YEAR AT USGS 06426130 DONKEY CREEK NEAR GILLETTE, WY

Calendar Year	Discharge (cfs)	Volume (Acre-ft)
2001	2.67	1,933
2002	0.504	365
2003	1.11	804
2004	0.699	506
2005	1.16	840
2006	0.751	544
2007	3.31	2,396
2008	2.86	2,071
2009	2.75	1,991
2010	2.17	1,571

Table C-3 shows the average discharge and total volume, at the same USGS Donkey Creek gage station, for the months April through September.

TABLE C-3 – USGS 06426130 DONKEY CREEK NEAR GILLETTE, WY APRIL - SEPTEMBER FLOW AND VOLUME

Calendar Year	Discharge (cfs)	Volume (Acre-ft)
2001	4.29	1,566
2002	0.57	208
2003	0.84	307
2004	0.40	146
2005	1.71	625
2006	1.06	386
2007	5.59	2,039
2008	4.51	1,647
2009	2.94	1,073
2010	3.36	1,227
2011	5.74	4,154

INLET FLOW

Table C-4 shows Gillette Fishing Lake inlet discharge measurements and associated staff gage readings.

TABLE C-4 – INLET STAGE-DISCHARGE MEASUREMENTS

Date	Time	Stage (ft)	Discharge (cfs)
6/19/2009	10:27 AM	0.34	0.16
7/30/2009	10:00 AM	0.36	0.26
11/21/2008	11:49 AM	0.40	0.15
5/26/2009	10:45 AM	0.46	0.79
8/17/2009	2:50 PM	0.48	0.60
7/8/2009	3:50 PM	0.50	0.69
4/21/2009	2:00 PM	0.56	1.14
6/8/2009	11:50 AM	0.60	1.22
6/11/2009	2:00 PM	0.66	1.22
7/6/2009	12:00 PM	0.70	1.82
7/7/2009	4:10 PM	0.84	2.59
6/10/2009	2:00 PM	0.88	3.05
6/9/2009	10:15 AM	0.92	3.10
4/10/2009	12:45 PM	1.20	47.95

Figures C-1 and C-2 displays the relationships between the staff gage readings and measured discharge at the inlet to the lake. These relationships were created in order to determine the associated flows for the other staff gage readings. The staff gage reading-discharge rating curve was separated into a low flow relationship and a high flow relationship in order to improve the accuracy of the relationship.

FIGURE C-1 – INLET STAGE-DISCHARGE CURVE FOR LOW FLOWS

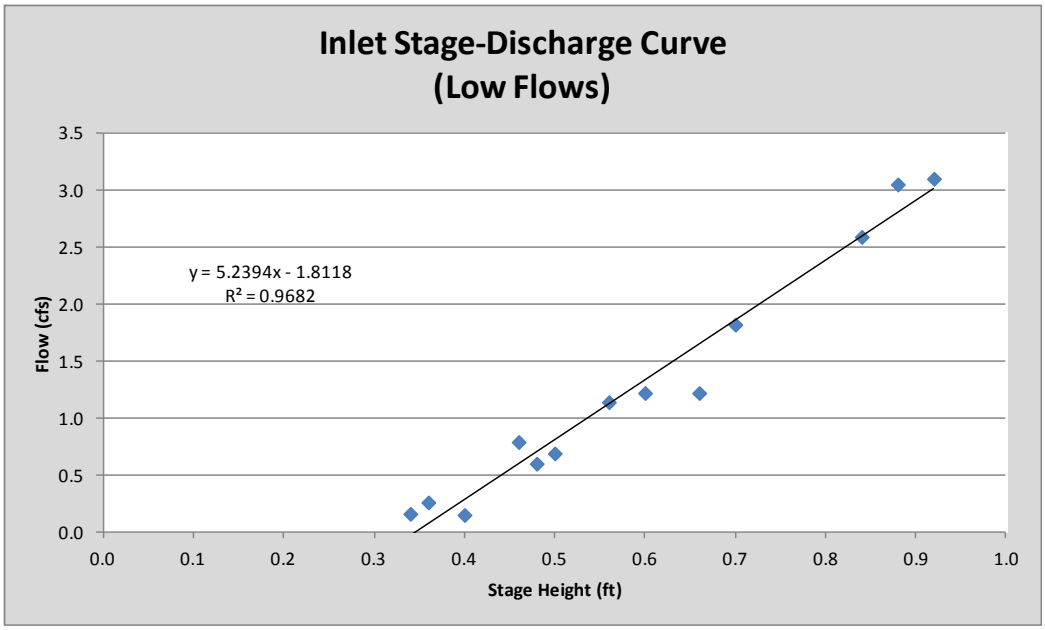


Figure C-2 – Inlet Stage-Discharge Curve for High Flows

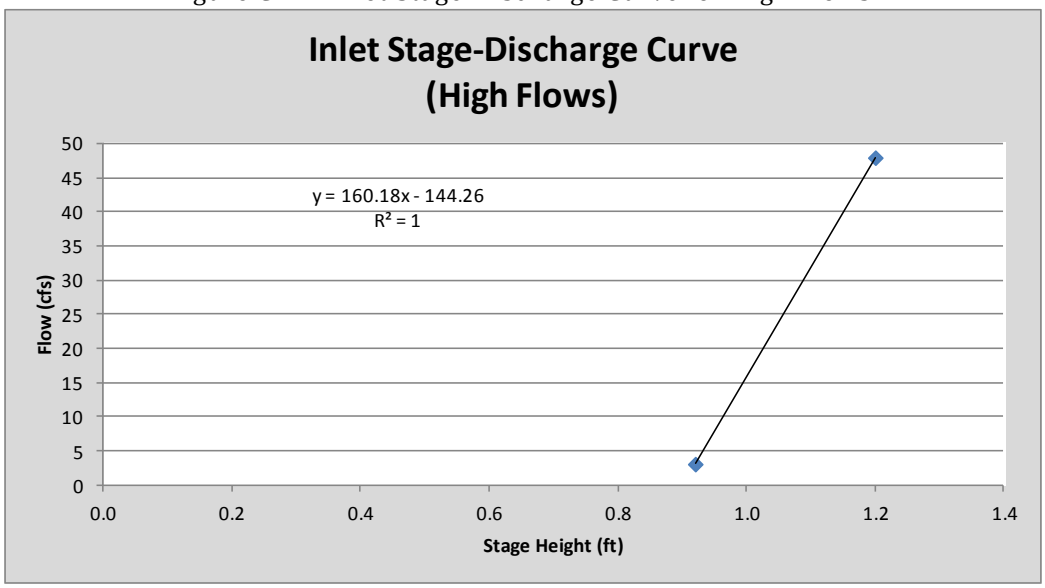


Table C-5 shows the inlet flows for all staff gage readings.

TABLE C-5 – INLET STAFF GAUGE READINGS AND ESTIMATED FLOWS

Source	Date	Flow at Inlet (cfs)
Flow Measurement	11/21/2008	0.15
Stage-Discharge Curve	11/24/2008	0.16
Stage-Discharge Curve	11/26/2008	0.16
Stage-Discharge Curve	12/1/2008	0.16
Stage-Discharge Curve	12/3/2008	0.16
Stage-Discharge Curve	12/5/2008	0.16
Stage-Discharge Curve	12/8/2008	0.39
Stage-Discharge Curve	12/9/2008	0.28
Stage-Discharge Curve	12/10/2008	0.28
Stage-Discharge Curve	12/12/2008	0.18
Stage-Discharge Curve	12/15/2008	0.16
Stage-Discharge Curve	12/17/2008	0.16
Stage-Discharge Curve	12/19/2008	0.16
Stage-Discharge Curve	12/22/2008	0.15
Stage-Discharge Curve	12/24/2008	0.15
Stage-Discharge Curve	12/26/2008	0.00
Stage-Discharge Curve	12/29/2008	0.15
Stage-Discharge Curve	12/31/2008	0.16
Stage-Discharge Curve	1/2/2009	0.16
Stage-Discharge Curve	1/5/2009	0.15
Stage-Discharge Curve	1/7/2009	0.15
Stage-Discharge Curve	1/9/2009	0.15
Stage-Discharge Curve	1/12/2009	1.44
Stage-Discharge Curve	1/14/2009	0.60
Stage-Discharge Curve	1/16/2009	0.60
Stage-Discharge Curve	1/20/2009	1.23
Stage-Discharge Curve	1/21/2009	1.75
Stage-Discharge Curve	1/26/2009	0.81
Stage-Discharge Curve	1/28/2009	0.49
Stage-Discharge Curve	1/30/2009	0.60
Stage-Discharge Curve	2/2/2009	0.70
Stage-Discharge Curve	2/4/2009	0.70
Stage-Discharge Curve	2/6/2009	5.00
Stage-Discharge Curve	2/9/2009	4.27
Stage-Discharge Curve	2/11/2009	2.90
Stage-Discharge Curve	2/13/2009	1.86
Stage-Discharge Curve	2/17/2009	1.12

Source	Date	Flow at Inlet (cfs)
Stage-Discharge Curve	2/18/2009	1.02
Stage-Discharge Curve	2/20/2009	1.02
Stage-Discharge Curve	2/23/2009	0.91
Stage-Discharge Curve	2/25/2009	1.44
Stage-Discharge Curve	2/27/2009	1.44
Stage-Discharge Curve	3/2/2009	1.75
Stage-Discharge Curve	3/4/2009	2.48
Stage-Discharge Curve	3/6/2009	2.38
Stage-Discharge Curve	3/9/2009	1.59
Stage-Discharge Curve	3/13/2009	0.70
Stage-Discharge Curve	3/16/2009	1.86
Stage-Discharge Curve	3/18/2009	1.75
Stage-Discharge Curve	3/20/2009	0.81
Stage-Discharge Curve	4/6/2009	1.86
Stage-Discharge Curve	4/7/2009	2.27
Stage-Discharge Curve	4/8/2009	2.90
Stage-Discharge Curve	4/9/2009	4.16
Stage-Discharge Curve	4/10/2009	4.48
Stage-Discharge Curve	4/13/2009	4.37
Stage-Discharge Curve	4/14/2009	4.27
Stage-Discharge Curve	4/15/2009	3.22
Stage-Discharge Curve	4/16/2009	3.11
Stage-Discharge Curve	4/17/2009	3.11
Stage-Discharge Curve	4/20/2009	1.44
Flow Measurement	4/21/2009	1.14
Stage-Discharge Curve	4/22/2009	0.70
Stage-Discharge Curve	4/23/2009	0.70
Stage-Discharge Curve	4/24/2009	1.54
Stage-Discharge Curve	4/27/2009	2.17
Stage-Discharge Curve	4/28/2009	1.65
Stage-Discharge Curve	4/29/2009	1.12
Stage-Discharge Curve	4/30/2009	0.81
Stage-Discharge Curve	5/1/2009	0.49
Stage-Discharge Curve	5/4/2009	0.60
Stage-Discharge Curve	5/5/2009	0.49
Stage-Discharge Curve	5/6/2009	0.28
Stage-Discharge Curve	5/7/2009	0.28
Stage-Discharge Curve	5/8/2009	1.86
Stage-Discharge Curve	5/11/2009	0.28

Source	Date	Flow at Inlet (cfs)
Stage-Discharge Curve	5/12/2009	0.28
Stage-Discharge Curve	5/13/2009	0.28
Stage-Discharge Curve	5/15/2009	0.60
Stage-Discharge Curve	5/18/2009	0.07
Stage-Discharge Curve	5/19/2009	0.07
Stage-Discharge Curve	5/20/2009	0.16
Stage-Discharge Curve	5/21/2009	0.16
Flow Measurement	5/26/2009	0.79
Stage-Discharge Curve	5/27/2009	0.18
Stage-Discharge Curve	5/28/2009	0.16
Stage-Discharge Curve	5/29/2009	0.16
Stage-Discharge Curve	6/1/2009	0.00
Stage-Discharge Curve	6/2/2009	0.00
Stage-Discharge Curve	6/3/2009	0.16
Stage-Discharge Curve	6/4/2009	0.16
Stage-Discharge Curve	6/5/2009	0.16
Stage-Discharge Curve	6/6/2009	1.33
Stage-Discharge Curve	6/7/2009	1.23
Flow Measurement	6/8/2009	1.22
Flow Measurement	6/9/2009	3.10
Flow Measurement	6/10/2009	3.05
Flow Measurement	6/11/2009	1.22
Stage-Discharge Curve	6/12/2009	0.70
Stage-Discharge Curve	6/15/2009	0.17
Stage-Discharge Curve	6/17/2009	0.17
Stage-Discharge Curve	6/18/2009	0.16
Flow Measurement	6/19/2009	0.16
Stage-Discharge Curve	6/22/2009	0.00
Stage-Discharge Curve	6/23/2009	0.00
Stage-Discharge Curve	6/24/2009	0.00
Stage-Discharge Curve	6/26/2009	0.00
Stage-Discharge Curve	6/29/2009	0.00
Stage-Discharge Curve	6/30/2009	0.00
Stage-Discharge Curve	7/1/2009	0.00
Stage-Discharge Curve	7/2/2009	0.00
Flow Measurement	7/6/2009	1.82
Flow Measurement	7/7/2009	2.59
Flow Measurement	7/8/2009	0.69
Stage-Discharge Curve	7/9/2009	0.15

Source	Date	Flow at Inlet (cfs)
Stage-Discharge Curve	7/10/2009	0.15
Stage-Discharge Curve	7/14/2009	0.00
Stage-Discharge Curve	7/15/2009	0.15
Stage-Discharge Curve	7/20/2009	0.00
Stage-Discharge Curve	7/23/2009	0.00
Stage-Discharge Curve	7/27/2009	0.28
Stage-Discharge Curve	7/28/2009	0.00
Stage-Discharge Curve	7/29/2009	0.49
Flow Measurement	7/30/2009	0.26
Stage-Discharge Curve	8/4/2009	0.00
Stage-Discharge Curve	8/6/2009	0.00
Stage-Discharge Curve	8/10/2009	1.23
Stage-Discharge Curve	8/11/2009	0.16
Stage-Discharge Curve	8/13/2009	0.00
Stage-Discharge Curve	8/14/2009	0.00
Flow Measurement	8/17/2009	0.60
Stage-Discharge Curve	8/19/2009	0.16
Stage-Discharge Curve	8/21/2009	0.00
Stage-Discharge Curve	8/24/2009	0.00
Stage-Discharge Curve	8/26/2009	0.00
Stage-Discharge Curve	8/31/2009	0.00
Stage-Discharge Curve	9/3/2009	0.00
Stage-Discharge Curve	9/8/2009	0.00
Stage-Discharge Curve	9/14/2009	0.00
Stage-Discharge Curve	9/15/2009	0.00
Stage-Discharge Curve	9/17/2009	0.00
Stage-Discharge Curve	9/21/2009	0.18
Stage-Discharge Curve	9/23/2009	0.00
Stage-Discharge Curve	9/25/2009	0.00
Stage-Discharge Curve	9/30/2009	0.00
Stage-Discharge Curve	10/1/2009	0.15
Stage-Discharge Curve	10/2/2009	0.00
Stage-Discharge Curve	10/5/2009	2.69
Stage-Discharge Curve	10/7/2009	0.70
Stage-Discharge Curve	10/9/2009	0.28
Stage-Discharge Curve	10/14/2009	0.49
Stage-Discharge Curve	10/19/2009	0.15
Stage-Discharge Curve	10/20/2009	0.81
Stage-Discharge Curve	10/23/2009	0.15

Staff gage measurements taken February 6th and 9th were assumed incorrect because though the staff gage readings implied high flows, precipitation data showed no precipitation for the 6th, and some precipitation on the 9th, but there were no commensurate increase in flow at the USGS gage. It is assumed that the inlet was ice affected causing erroneous readings. Flow measured From April 9 through April 14 was derived from the stage-discharge curve because the staff gage readings indicated that the flow at the inlet was greater than the flow both at the lake outlet and at the USGS gage and there was only trace amounts of precipitation between April 9 and April 14, 2009.

In order to create a continuous record of flow at the inlet, the inlet flows that were estimated based on the staff gage discharge rating curve were plotted against the corresponding USGS gage at Donkey Creek near Gillette, WY flows. By plotting the two datasets, two relationships between the inlet flow and the flow at the USGS gage were created, one for low flows and one for high flows.

FIGURE C-3 – LINEAR REGRESSION METHOD FOR ESTIMATING FLOWS AT INLET FOR LOW FLOWS

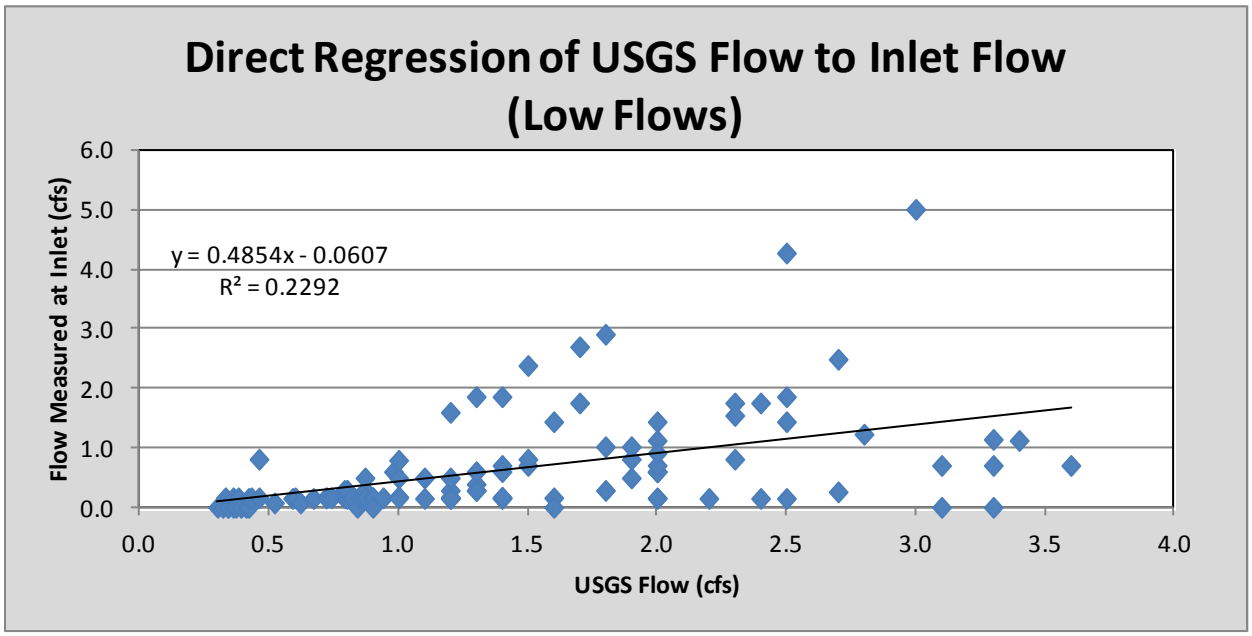
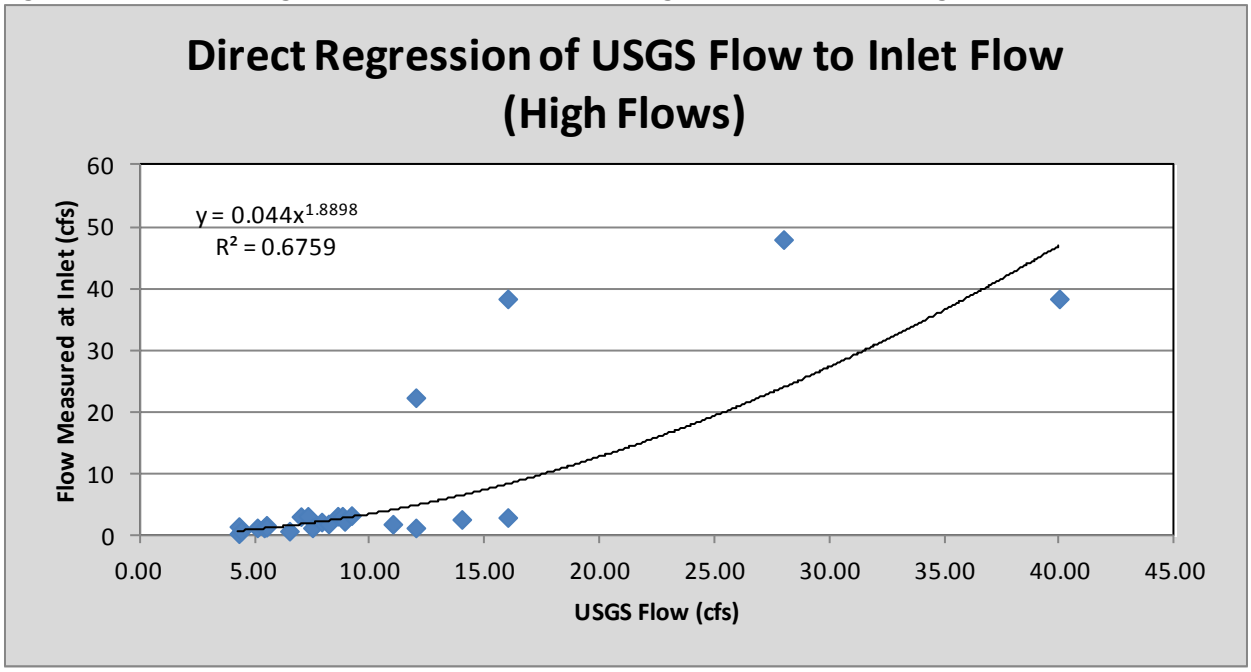


Figure C-4 – Linear Regression Method for Estimating Flows at Inlet for High Flows



From the two relationships between the inlet flow and the flow at the USGS gage, the average annual discharge and volume at the inlet was calculated.

TABLE C-6 – ANNUAL AVERAGE DISCHARGE AND TOTAL ANNUAL VOLUME

Year	Discharge (cfs)	Annual Sum of Volume (acre-ft)
2001	1.94	1,404
2002	0.19	135
2003	0.39	286
2004	0.25	178
2005	0.44	319
2006	0.30	220
2007	2.08	1,505
2008	1.71	1,242
2009	0.89	641
2010	1.01	731
Average	0.92	666

OUTLET FLOW

Table C-7 shows Gillette Fishing Lake outlet discharge measurements and associated staff gage readings.

TABLE C-7 – OUTLET STAGE-DISCHARGE MEASUREMENTS

Date	Time	Stage (ft)	Discharge (cfs)
7/30/2009	9:30 AM	0.86	0.22
11/13/2009	9:15 AM	0.94	0.85
5/26/2009	9:45 AM	0.94	0.57
10/23/2008	3:08 PM	0.96	0.40
8/17/2009	2:15 PM	0.98	0.64
7/6/2009	11:30 AM	1.04	0.87
6/8/2009	10:59 AM	1.14	1.70
7/8/2009	3:20 PM	1.16	2.01
7/7/2009	3:45 PM	1.22	3.20
6/9/2009	9:33 AM	1.22	3.20
6/10/2009	1:36 PM	1.30	4.40
4/21/2009	2:45 PM	1.30	6.51
4/10/2009	11:15 AM	1.84	28.77

Figures C-5 and C-6 shows the relationships between the staff gage readings at the outlet to the lake and the associated staff gage readings. These relationships were created in order to convert the numerous other staff gage readings that were taken into associated flow rates. The staff gage reading-discharge rating curve was separated into a low flow relationship and a high flow relationship in order to improve the accuracy of the relationship.

FIGURE C-5 – LINEAR REGRESSION METHOD FOR ESTIMATING FLOWS AT INLET FOR LOW FLOWS

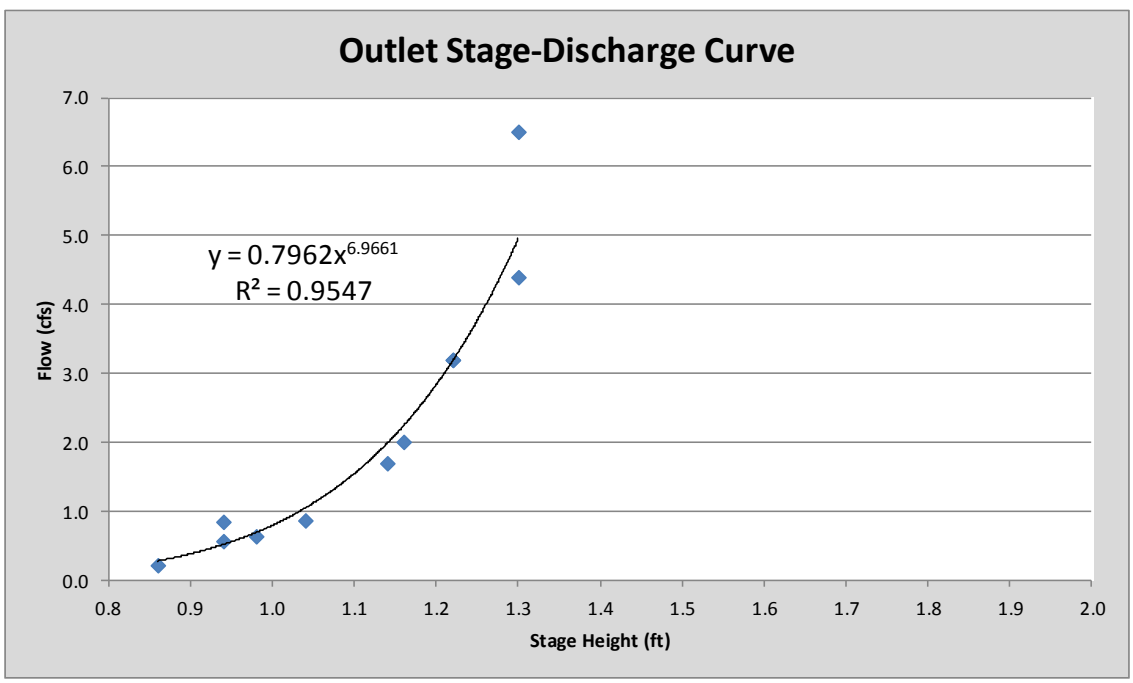


Figure C-6 – Linear Regression Method for Estimating Flows at Inlet for Low Flows

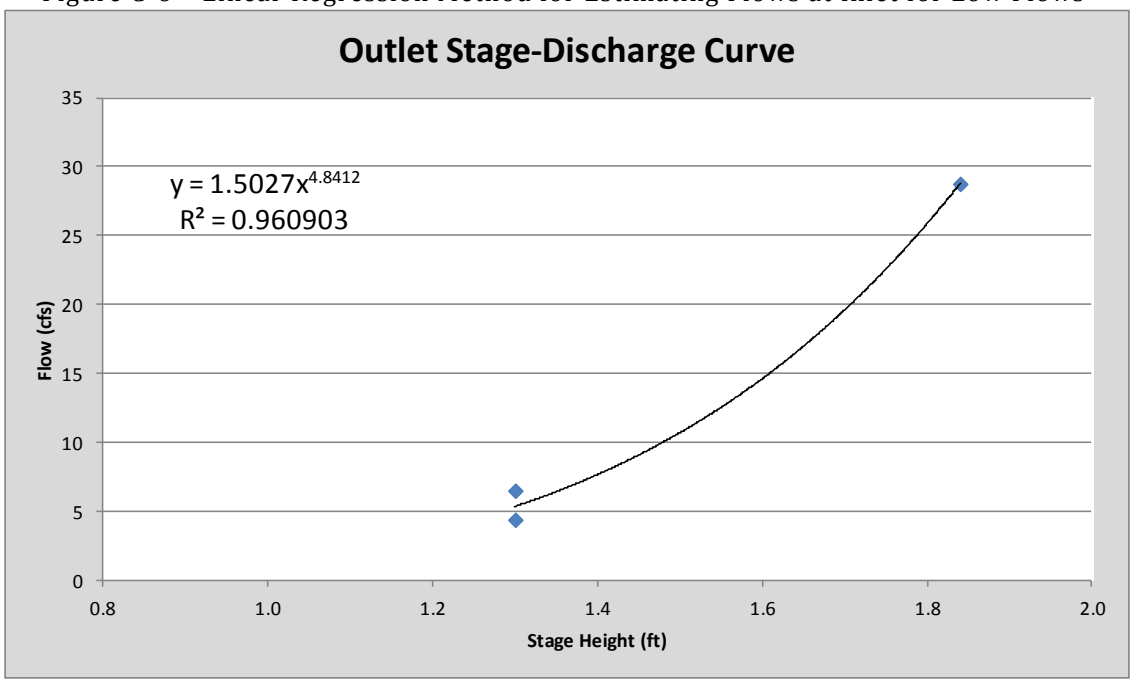


Table C-8 shows the outlet flows for all staff gage readings.

TABLE C-8 – OUTLET STAFF GAUGE READINGS AND ESTIMATED FLOWS

Source	Date	Flow (cfs)
Stage-Discharge Curve	10/28/2008	0.60
Stage-Discharge Curve	10/31/2008	0.00
Stage-Discharge Curve	11/4/2008	0.00
Stage-Discharge Curve	11/5/2008	0.00
Stage-Discharge Curve	11/7/2008	0.52
Stage-Discharge Curve	11/10/2008	0.00
Stage-Discharge Curve	11/12/2008	0.00
Stage-Discharge Curve	11/13/2008	0.52
Stage-Discharge Curve	11/14/2008	0.91
Stage-Discharge Curve	11/17/2008	0.52
Stage-Discharge Curve	11/24/2008	0.38
Stage-Discharge Curve	11/26/2008	0.38
Stage-Discharge Curve	12/1/2008	0.33
Stage-Discharge Curve	12/3/2008	0.45
Stage-Discharge Curve	12/5/2008	0.45
Stage-Discharge Curve	12/8/2008	0.69
Stage-Discharge Curve	12/9/2008	0.69
Stage-Discharge Curve	12/10/2008	0.69
Stage-Discharge Curve	12/12/2008	0.60

Source	Date	Flow (cfs)
Stage-Discharge Curve	12/15/2008	0.69
Stage-Discharge Curve	12/17/2008	0.69
Stage-Discharge Curve	12/19/2008	0.45
Stage-Discharge Curve	12/22/2008	0.45
Stage-Discharge Curve	12/24/2008	0.33
Stage-Discharge Curve	12/26/2008	0.28
Stage-Discharge Curve	12/29/2008	0.28
Stage-Discharge Curve	12/31/2008	0.33
Stage-Discharge Curve	1/2/2009	0.33
Stage-Discharge Curve	1/5/2009	0.38
Stage-Discharge Curve	1/7/2009	0.38
Stage-Discharge Curve	1/9/2009	0.38
Stage-Discharge Curve	1/12/2009	2.84
Stage-Discharge Curve	1/14/2009	1.19
Stage-Discharge Curve	1/16/2009	2.84
Stage-Discharge Curve	1/20/2009	1.19
Stage-Discharge Curve	1/21/2009	1.36
Stage-Discharge Curve	1/26/2009	1.75
Stage-Discharge Curve	1/28/2009	1.36
Stage-Discharge Curve	1/30/2009	1.45
Stage-Discharge Curve	2/2/2009	0.80
Stage-Discharge Curve	2/4/2009	0.91
Stage-Discharge Curve	2/6/2009	11.41
Stage-Discharge Curve	2/9/2009	16.48
Stage-Discharge Curve	2/11/2009	5.51
Stage-Discharge Curve	2/13/2009	2.84
Stage-Discharge Curve	2/17/2009	1.19
Stage-Discharge Curve	2/18/2009	1.05
Stage-Discharge Curve	2/20/2009	1.19
Stage-Discharge Curve	2/23/2009	0.80
Stage-Discharge Curve	2/25/2009	0.91
Stage-Discharge Curve	2/27/2009	0.80
Stage-Discharge Curve	3/2/2009	1.55
Stage-Discharge Curve	3/4/2009	1.98
Stage-Discharge Curve	3/6/2009	1.98
Stage-Discharge Curve	3/9/2009	1.05
Stage-Discharge Curve	3/11/2009	0.91
Stage-Discharge Curve	3/13/2009	0.91
Stage-Discharge Curve	3/16/2009	1.05

Source	Date	Flow (cfs)
Stage-Discharge Curve	3/18/2009	0.80
Stage-Discharge Curve	3/20/2009	0.69
Stage-Discharge Curve	4/2/2009	2.84
Stage-Discharge Curve	4/3/2009	2.84
Stage-Discharge Curve	4/6/2009	1.98
Stage-Discharge Curve	4/7/2009	2.84
Stage-Discharge Curve	4/8/2009	6.12
Stage-Discharge Curve	4/9/2009	24.50
Flow Measurement	4/10/2009	28.77
Stage-Discharge Curve	4/13/2009	16.48
Stage-Discharge Curve	4/14/2009	10.03
Stage-Discharge Curve	4/15/2009	7.15
Stage-Discharge Curve	4/16/2009	6.12
Stage-Discharge Curve	4/17/2009	5.51
Stage-Discharge Curve	4/20/2009	1.98
Flow Measurement	4/21/2009	6.51
Stage-Discharge Curve	4/22/2009	1.98
Stage-Discharge Curve	4/23/2009	1.36
Stage-Discharge Curve	4/24/2009	1.19
Stage-Discharge Curve	4/27/2009	4.45
Stage-Discharge Curve	4/28/2009	2.84
Stage-Discharge Curve	4/29/2009	1.75
Stage-Discharge Curve	4/30/2009	1.36
Stage-Discharge Curve	5/1/2009	1.05
Stage-Discharge Curve	5/4/2009	0.91
Stage-Discharge Curve	5/5/2009	0.80
Stage-Discharge Curve	5/6/2009	0.69
Stage-Discharge Curve	5/7/2009	0.69
Stage-Discharge Curve	5/8/2009	1.36
Stage-Discharge Curve	5/11/2009	0.91
Stage-Discharge Curve	5/12/2009	0.60
Stage-Discharge Curve	5/13/2009	0.80
Stage-Discharge Curve	5/15/2009	0.60
Stage-Discharge Curve	5/18/2009	0.33
Stage-Discharge Curve	5/19/2009	0.28
Stage-Discharge Curve	5/20/2009	0.28
Stage-Discharge Curve	5/21/2009	0.24
Flow Measurement	5/26/2009	0.57
Stage-Discharge Curve	5/27/2009	0.45

Source	Date	Flow (cfs)
Stage-Discharge Curve	5/28/2009	0.28
Stage-Discharge Curve	5/29/2009	0.24
Stage-Discharge Curve	6/1/2009	0.00
Stage-Discharge Curve	6/2/2009	0.00
Stage-Discharge Curve	6/3/2009	0.00
Stage-Discharge Curve	6/4/2009	0.00
Stage-Discharge Curve	6/5/2009	0.00
Stage-Discharge Curve	6/6/2009	1.98
Flow Measurement	6/8/2009	1.70
Flow Measurement	6/9/2009	3.20
Flow Measurement	6/10/2009	4.40
Stage-Discharge Curve	6/11/2009	3.98
Stage-Discharge Curve	6/12/2009	1.75
Stage-Discharge Curve	6/15/2009	0.60
Stage-Discharge Curve	6/17/2009	0.33
Stage-Discharge Curve	6/18/2009	0.28
Stage-Discharge Curve	6/22/2009	0.00
Stage-Discharge Curve	6/23/2009	0.00
Stage-Discharge Curve	6/24/2009	0.00
Stage-Discharge Curve	6/26/2009	0.00
Stage-Discharge Curve	6/29/2009	0.00
Stage-Discharge Curve	6/30/2009	0.00
Stage-Discharge Curve	7/1/2009	0.00
Stage-Discharge Curve	7/2/2009	0.00
Flow Measurement	7/6/2009	0.87
Flow Measurement	7/7/2009	3.20
Flow Measurement	7/8/2009	2.01
Stage-Discharge Curve	7/9/2009	1.19
Stage-Discharge Curve	7/10/2009	0.80
Stage-Discharge Curve	7/14/2009	2.24
Stage-Discharge Curve	7/15/2009	1.36
Stage-Discharge Curve	7/20/2009	0.00
Stage-Discharge Curve	7/22/2009	0.00
Stage-Discharge Curve	7/23/2009	0.00
Stage-Discharge Curve	7/27/2009	0.00
Stage-Discharge Curve	7/28/2009	0.00
Stage-Discharge Curve	7/29/2009	0.00
Flow Measurement	7/30/2009	0.22
Stage-Discharge Curve	8/4/2009	0.00

Source	Date	Flow (cfs)
Stage-Discharge Curve	8/6/2009	0.00
Stage-Discharge Curve	8/10/2009	1.98
Stage-Discharge Curve	8/11/2009	0.80
Stage-Discharge Curve	8/13/2009	0.69
Stage-Discharge Curve	8/14/2009	0.60
Flow Measurement	8/17/2009	0.64
Stage-Discharge Curve	8/19/2009	0.60
Stage-Discharge Curve	8/21/2009	0.38
Stage-Discharge Curve	8/24/2009	0.00
Stage-Discharge Curve	8/26/2009	0.45
Stage-Discharge Curve	8/31/2009	0.33
Stage-Discharge Curve	9/3/2009	0.00
Stage-Discharge Curve	9/8/2009	0.00
Stage-Discharge Curve	9/14/2009	0.00
Stage-Discharge Curve	9/15/2009	0.00
Stage-Discharge Curve	9/17/2009	0.00
Stage-Discharge Curve	9/21/2009	0.00
Stage-Discharge Curve	9/23/2009	0.00
Stage-Discharge Curve	9/25/2009	0.00
Stage-Discharge Curve	9/30/2009	0.00
Stage-Discharge Curve	10/1/2009	0.00
Stage-Discharge Curve	10/2/2009	0.00
Stage-Discharge Curve	10/5/2009	0.12
Stage-Discharge Curve	10/7/2009	1.75
Stage-Discharge Curve	10/9/2009	1.19
Stage-Discharge Curve	10/14/2009	0.38
Stage-Discharge Curve	10/19/2009	0.38
Stage-Discharge Curve	10/20/2009	0.60
Stage-Discharge Curve	10/23/2009	0.45

In order to create a continuous record of flow at the outlet, the outlet flows that were estimated based on the staff gage discharge rating curve were plotted against the corresponding USGS gage at Donkey Creek near Gillette, WY flows. By plotting the two datasets, two relationships between the outlet flow and the flow at the USGS gage were created, one for low flows and one for high flows.

FIGURE C-7 – LINEAR REGRESSION METHOD FOR ESTIMATING FLOWS AT INLET FOR LOW FLOWS

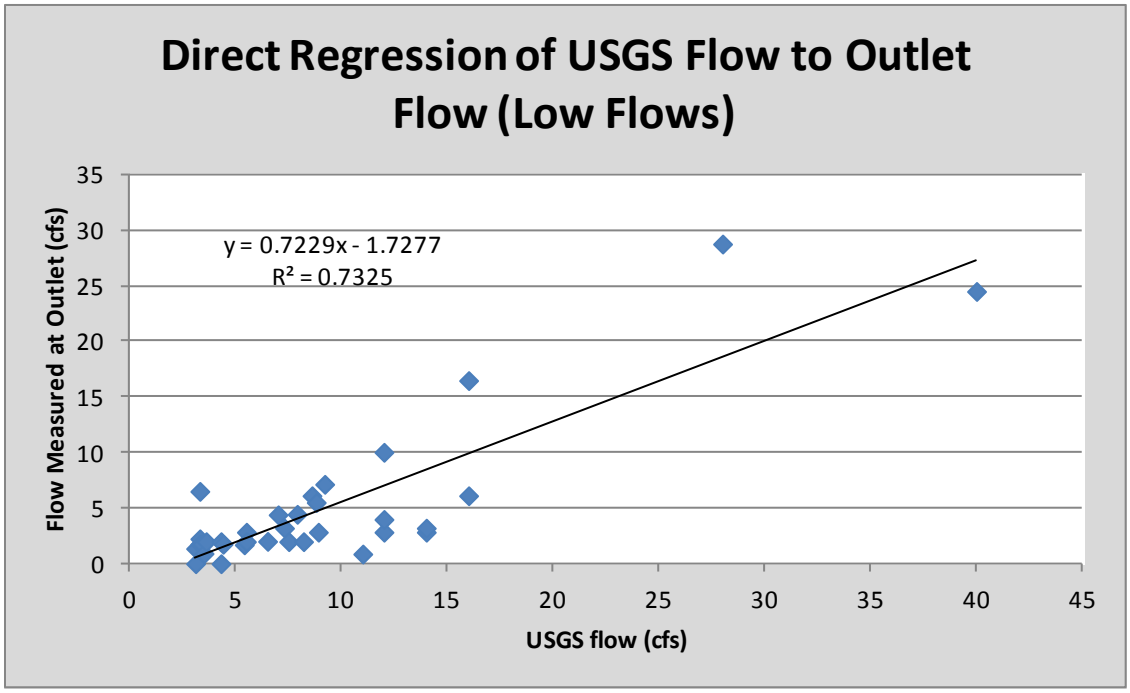
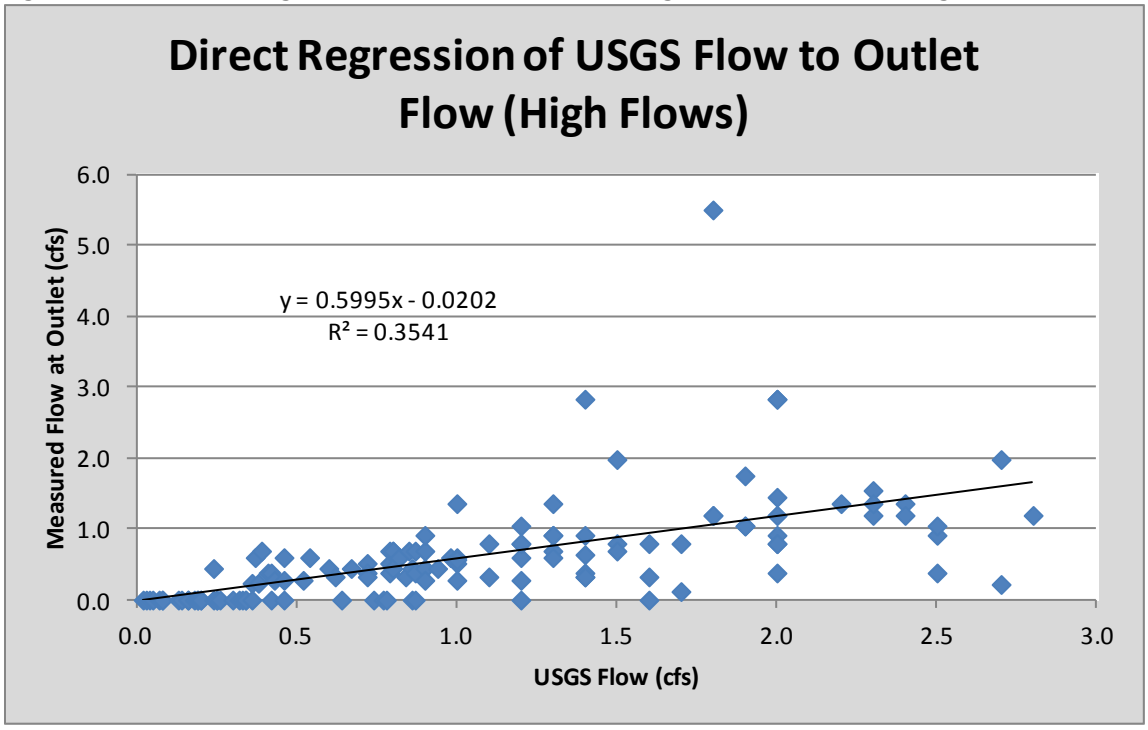


Figure C-8 – Linear Regression Method for Estimating Flows at Inlet for High Flows



From the two relationships between the inlet flow and the flow at the USGS gage, the average annual discharge and volume at the inlet was calculated.

TABLE C-9 – ANNUAL AVERAGE FLOW AND VOLUME AT GILLETTE FISHING LAKE OUTLET

Year	Discharge (cfs)	Annual Sum of Volume (acre-ft)
2001	1.65	1,196
2002	0.25	181
2003	0.54	390
2004	0.30	221
2005	0.58	422
2006	0.37	271
2007	1.94	1,402
2008	1.63	1,187
2009	1.63	1,182
2010	1.14	824
Average	1.00	728

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1. WATERSHED LOADING CALCULATIONS

RUSLE

RUSLE computes sheet and rill erosion from rainfall and the associated runoff for each identified land use. As a revision and update of the widely used Universal Soil Loss Equation (USLE), RUSLE incorporates data from rangeland and other research sites in the United States to significantly improve erosion estimates on untilled lands. RUSLE was chosen as the model to determine the sediment loading from the watershed due to its applicability to the rangeland areas as well as the urban areas. The factors utilized for the equation were versatile in order to demonstrate the loading coming from the watershed.

The RUSLE is written as: A = RE*K*LS*C*P

Where:
A = annual soil loss from sheet and rill erosion in tons/acre
RE = rainfall erosivity factor
K = soil erodibility factor
LS = slope length and steepness factor
C = cover and management factor
P = support practice factor

The following is a discussion of each factor for RUSLE:

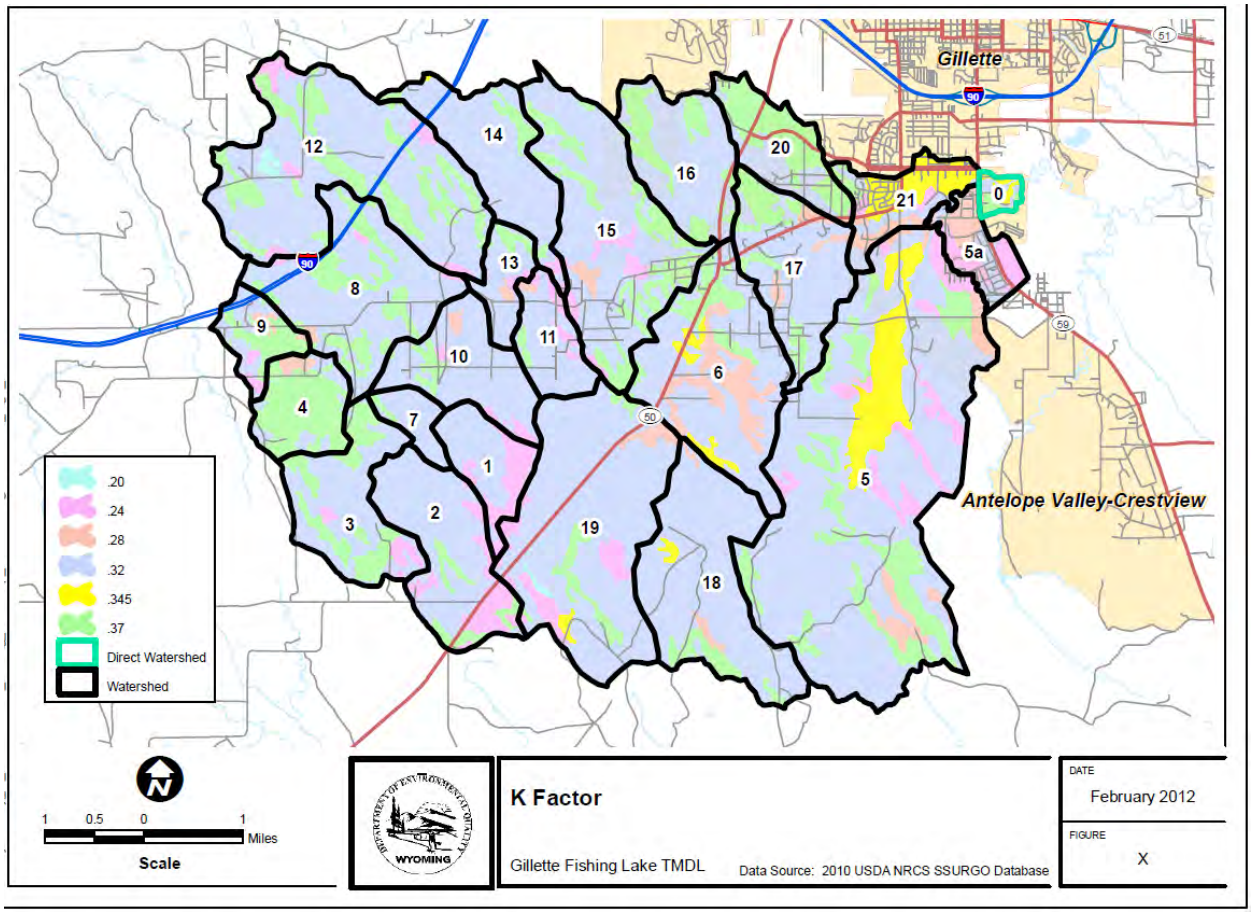
RE FACTOR

The entire watershed was assigned an RE value of 32 based on guidance from WDEQ/WQD (WDEQ, 2009).

K FACTOR

K values for the soils in the watershed are provided by Soil Survey Geographic (SSURGO) Database (USDA NRCS, 2009). The soil related K factors were really averaged based on area, land use, soil type, and subbasin. The results of the area-weighted average of the K factors provided by NRCS are shown in Figure D-1.

Figure D-1 K factors



The K factors were then delineated by subbasin and land use. Table D-1 shows the area-weighted K factor for each subbasin for each land use.

TABLE D-1 – SOIL K FACTORS BY SUBBASIN AND LAND USE

Subbasin	Construction	Road	Rural Residential	Upland Shrub	Urban	Water	Wyoming Big Sage Brush
Direct Watershed	0.34	0.34	0.00	0.00	0.34	0.00	0.00
Subbasin 1	0.32	0.29	0.32	0.29	0.00	0.00	0.00
Subbasin 2	0.32	0.30	0.32	0.31	0.00	0.00	0.00
Subbasin 3	0.32	0.33	0.32	0.33	0.00	0.00	0.00
Subbasin 4	0.36	0.00	0.36	0.35	0.00	0.00	0.00
Subbasin 5	0.31	0.31	0.00	0.32	0.31	0.00	0.32
Subbasin 5a	0.29	0.28	0.00	0.00	0.29	0.00	0.28
Subbasin 6	0.33	0.33	0.33	0.00	0.34	0.00	0.31
Subbasin 7	0.33	0.32	0.33	0.32	0.00	0.00	0.00
Subbasin 8	0.33	0.34	0.33	0.33	0.33	0.00	0.32
Subbasin 9	0.33	0.33	0.00	0.33	0.33	0.00	0.00
Subbasin 10	0.32	0.31	0.32	0.29	0.00	0.00	0.32
Subbasin 11	0.31	0.30	0.31	0.00	0.30	0.00	0.27
Subbasin 12	0.33	0.32	0.00	0.33	0.00	0.00	0.33
Subbasin 13	0.31	0.32	0.31	0.00	0.00	0.00	0.33
Subbasin 14	0.26	0.31	0.26	0.33	0.00	0.00	0.32
Subbasin 15	0.33	0.33	0.33	0.00	0.33	0.00	0.32
Subbasin 16	0.33	0.33	0.32	0.00	0.33	0.00	0.33
Subbasin 17	0.33	0.32	0.33	0.00	0.31	0.00	0.33
Subbasin 18	0.32	0.32	0.00	0.33	0.00	0.00	0.32
Subbasin 19	0.32	0.32	0.32	0.31	0.00	0.00	0.31
Subbasin 20	0.34	0.35	0.32	0.00	0.34	0.00	0.36
Subbasin 21	0.32	0.33	0.00	0.00	0.32	0.00	0.30

LS FACTOR

Moore and Burch (1986) proposed a methodology to calculate the LS factor using an equation. This method has been adopted and evaluated widely. An example of the use of this approach is shown by Van Remortel and Hamilton (2001). This methodology is described in detail in reports from professors at North Carolina State University and Purdue University (Engel, 2003; Mitasova and Brown, No date).

The equation is based on flow accumulation and slope steepness, all values that can be calculated using standard GIS functions based on elevation. The equation for the LS factor is:

LS = (Flow Accumulation * Cell Size/22.13)^0.4 * (sin slope/0.0896)^1.3

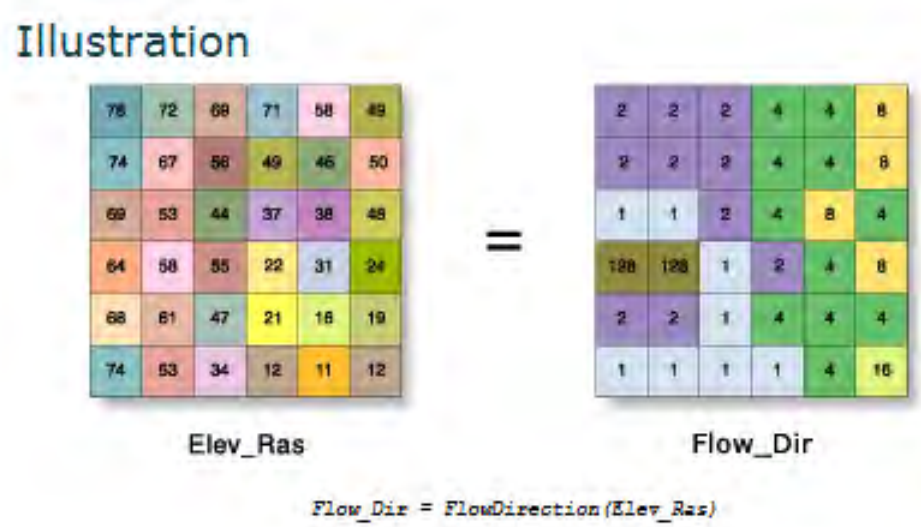
Where:

Flow Accumulation = flow accumulation (flow direction (elevation))

Here, flow accumulation, flow direction, and slope are standard, prepackaged GIS spatial functions available in ESRI's ArcMap GIS software. Cell size is based on the resolution of the elevation data, which in this case was 10 meters.

Flow direction takes a surface as input and outputs a raster showing the direction of flow out of each cell. From the ArcMap help file:

CREATES A RASTER OF FLOW DIRECTION FROM EACH CELL TO ITS STEEPEST DOWNSLOPE NEIGHBOR.



THE OUTPUT OF THE FLOW DIRECTION TOOL IS AN INTEGER RASTER WHOSE VALUES RANGE FROM 1 TO 255. THE VALUES FOR EACH DIRECTION FROM THE CENTER ARE:

32	64	128
16		1
8	4	2

FOR EXAMPLE, IF THE DIRECTION OF STEEPEST DROP WAS TO THE LEFT OF THE CURRENT PROCESSING CELL, ITS FLOW DIRECTION WOULD BE CODED AS 16.

IF A CELL IS LOWER THAN ITS EIGHT NEIGHBORS, THAT CELL IS GIVEN THE VALUE OF ITS LOWEST NEIGHBOR, AND FLOW IS DEFINED TOWARD THIS CELL. IF MULTIPLE NEIGHBORS HAVE THE LOWEST VALUE, THE CELL IS STILL GIVEN THIS VALUE, BUT FLOW IS DEFINED WITH ONE OF THE TWO METHODS EXPLAINED BELOW. THIS IS USED TO FILTER OUT ONE-CELL SINKS, WHICH ARE CONSIDERED NOISE.

IF A CELL HAS THE SAME CHANGE IN Z-VALUE IN MULTIPLE DIRECTIONS AND THAT CELL IS PART OF A SINK, THE FLOW DIRECTION IS REFERRED TO AS UNDEFINED. IN SUCH CASES, THE VALUE FOR THAT CELL IN THE OUTPUT FLOW DIRECTION RASTER WILL BE THE SUM OF THOSE DIRECTIONS. FOR EXAMPLE, IF THE CHANGE IN Z-VALUE IS THE SAME BOTH TO THE RIGHT (FLOW DIRECTION = 1) AND DOWN (FLOW DIRECTION = 4), THE FLOW DIRECTION FOR THAT CELL IS 1 + 4 = 5. CELLS WITH UNDEFINED FLOW DIRECTION CAN BE FLAGGED AS SINKS USING THE SINK TOOL.

IF A CELL HAS THE SAME CHANGE IN Z-VALUE IN MULTIPLE DIRECTIONS AND IS NOT PART OF A SINK, THE FLOW DIRECTION IS ASSIGNED WITH A LOOKUP TABLE DEFINING THE MOST LIKELY DIRECTION. SEE GREENLEE (1987).

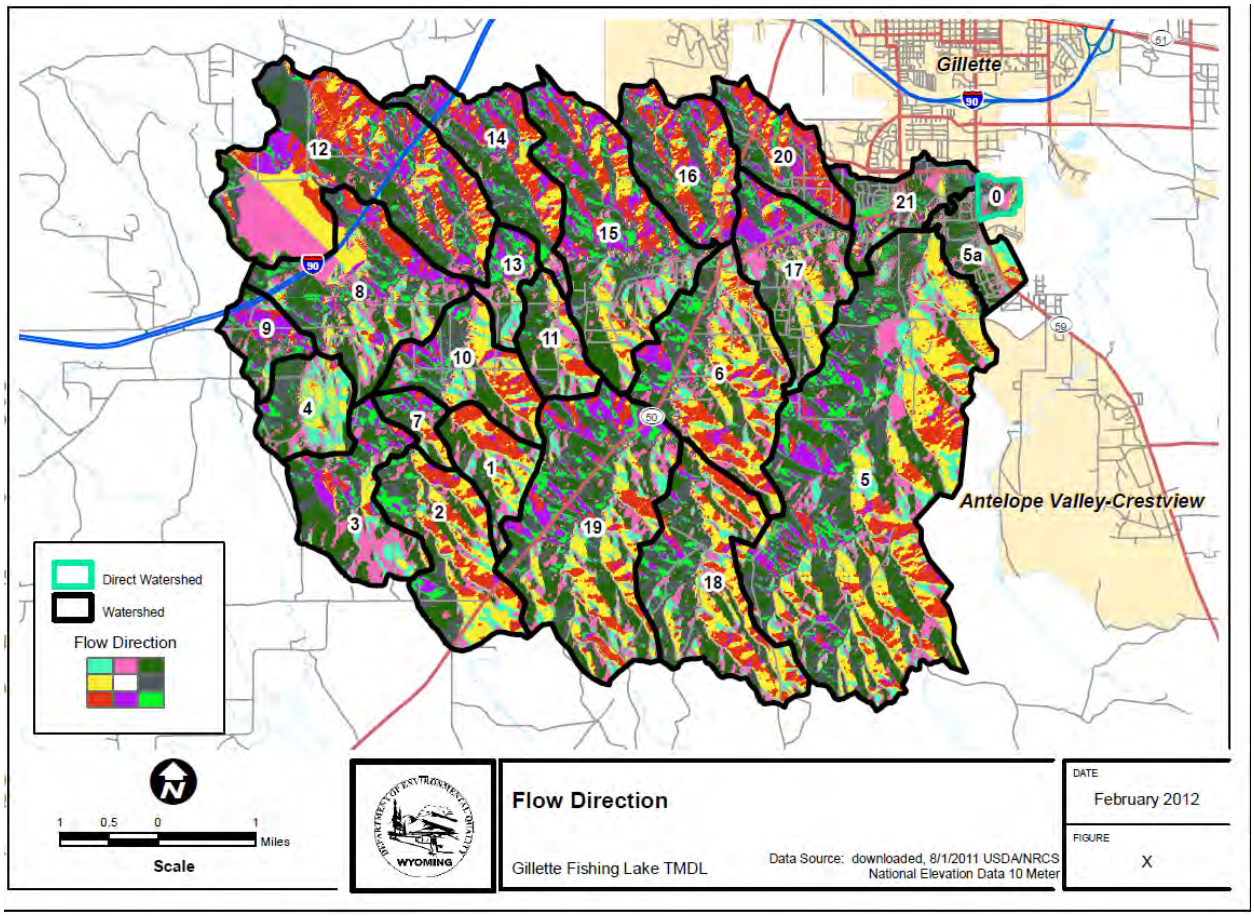
THE OUTPUT DROP RASTER IS CALCULATED AS THE DIFFERENCE IN Z-VALUE DIVIDED BY THE PATH LENGTH BETWEEN THE CELL CENTERS, EXPRESSED IN PERCENTAGES. FOR ADJACENT CELLS, THIS IS ANALOGOUS TO THE PERCENT SLOPE BETWEEN CELLS. ACROSS A FLAT AREA, THE DISTANCE BECOMES THE DISTANCE TO THE

NEAREST CELL OF LOWER ELEVATION. THE RESULT IS A MAP OF PERCENT RISE IN THE PATH OF STEEPEST DESCENT FROM EACH CELL.

WHEN CALCULATING THE DROP RASTER IN FLAT AREAS, THE DISTANCE TO DIAGONALLY ADJACENT CELLS (1.414 * CELL SIZE) IS APPROXIMATED BY 1.5 * CELL SIZE TO INCREASE THE PROCESSING SPEED BY USING INTEGER CALCULATIONS.

WHEN USING THE NORMAL OPTION, A CELL AT THE EDGE OF THE SURFACE RASTER WILL FLOW TOWARD THE INNER CELL WITH THE STEEPEST DROP IN Z-VALUE. IF THE DROP IS LESS THAN OR EQUAL TO ZERO, THE CELL WILL FLOW OUT OF THE SURFACE RASTER.

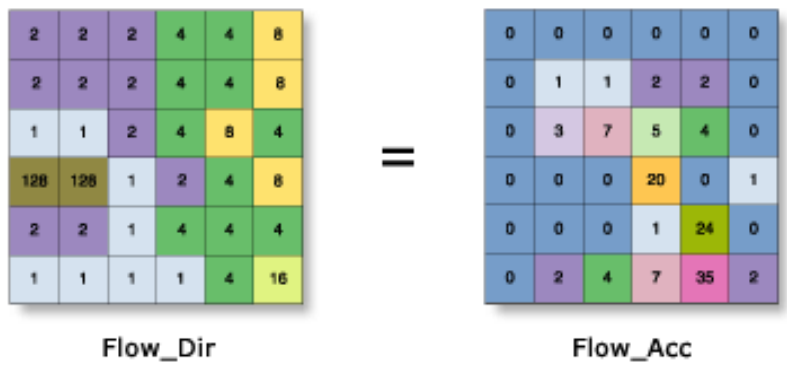
Figure D-2 shows the results of applying the flow direction tool to the Gillette Fishing Lake watershed.



The Flow Accumulation tool calculates accumulated flow as the accumulated weight of all cells flowing into each downslope cell in the output raster. From the ArcMap help files:

CREATES A RASTER OF ACCUMULATED FLOW INTO EACH CELL. A WEIGHT FACTOR CAN OPTIONALLY BE APPLIED.

Illustration



Flow_Acc = FlowAccumulation(Flow_Dir)

USAGE

THE RESULT OF FLOW ACCUMULATION IS A RASTER OF ACCUMULATED FLOW TO EACH CELL, AS DETERMINED BY ACCUMULATING THE WEIGHT FOR ALL CELLS THAT FLOW INTO EACH DOWNSLOPE CELL.

CELLS OF UNDEFINED FLOW DIRECTION WILL ONLY RECEIVE FLOW; THEY WILL NOT CONTRIBUTE TO ANY DOWNSTREAM FLOW. A CELL IS CONSIDERED TO HAVE AN UNDEFINED FLOW DIRECTION IF ITS VALUE IN THE FLOW DIRECTION RASTER IS ANYTHING OTHER THAN 1, 2, 4, 8, 16, 32, 64, OR 128.

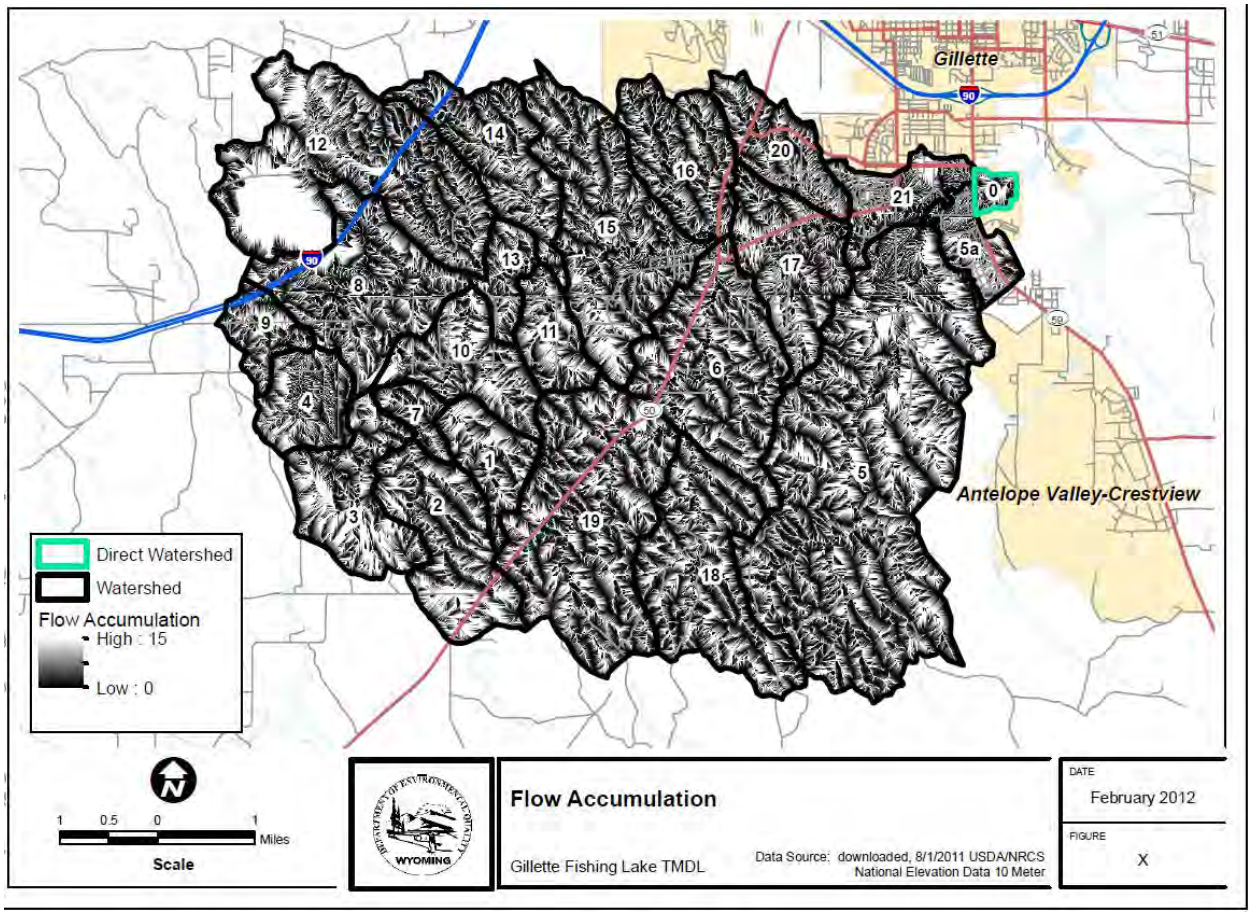
THE ACCUMULATED FLOW IS BASED ON THE NUMBER OF CELLS FLOWING INTO EACH CELL IN THE OUTPUT RASTER. THE CURRENT PROCESSING CELL IS NOT CONSIDERED IN THIS ACCUMULATION.

OUTPUT CELLS WITH A HIGH FLOW ACCUMULATION ARE AREAS OF CONCENTRATED FLOW AND CAN BE USED TO IDENTIFY STREAM CHANNELS.

OUTPUT CELLS WITH A FLOW ACCUMULATION OF ZERO ARE LOCAL TOPOGRAPHIC HIGHS AND CAN BE USED TO IDENTIFY RIDGES.

IF THE INPUT FLOW DIRECTION RASTER IS NOT CREATED WITH THE FLOW DIRECTION TOOL, THERE IS A CHANCE THAT THE DEFINED FLOW COULD LOOP. IF THE FLOW DIRECTION DOES LOOP, FLOW ACCUMULATION WILL GO INTO AN INFINITE LOOP AND NEVER FINISH.

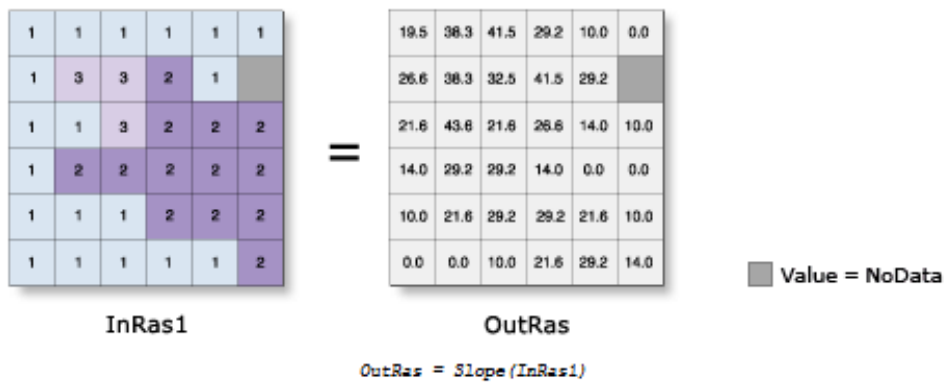
Figure D-3 shows the results of applying the flow accumulation tool to the Gillette Fishing Lake watershed. As described in the North Carolina State University and Purdue University methodologies, because RUSLE is used to estimate only sheet and rill erosion, a maximum flow accumulation of 150 meters was used. This translates to a maximum of 15 cells.



Slope represents the rate of change of elevation for each DEM cell. From the ArcMap help files:

IDENTIFIES THE SLOPE (GRADIENT, OR RATE OF MAXIMUM CHANGE IN Z-VALUE) FROM EACH CELL OF A RASTER SURFACE.

Illustration



USAGE

SLOPE IS THE RATE OF MAXIMUM CHANGE IN Z-VALUE FROM EACH CELL.

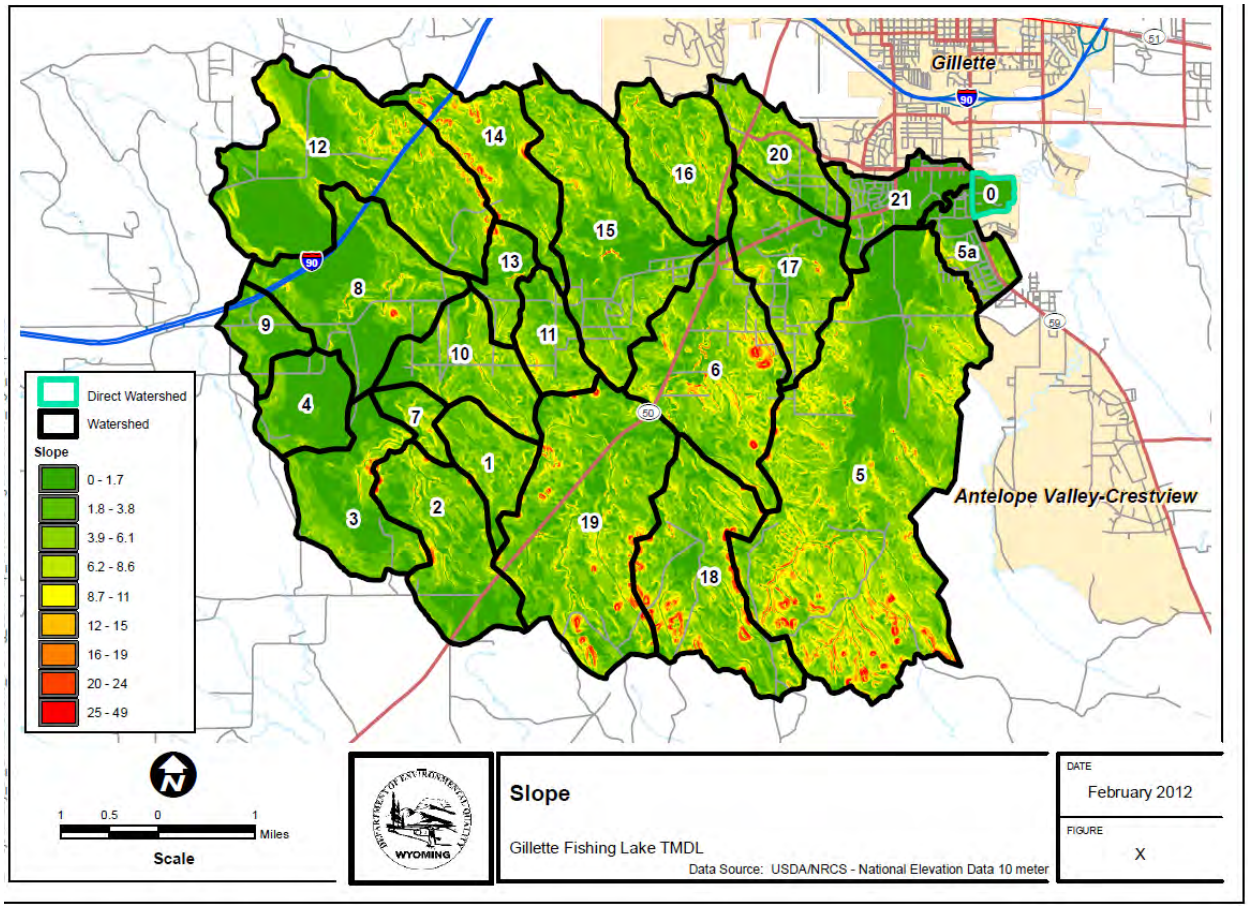
THE USE OF A Z-FACTOR IS ESSENTIAL FOR CORRECT SLOPE CALCULATIONS WHEN THE SURFACE Z UNITS ARE EXPRESSED IN UNITS DIFFERENT FROM THE GROUND X,Y UNITS.

THE RANGE OF SLOPE VALUES IN DEGREES IS 0 TO 90. FOR PERCENT RISE, THE RANGE IS 0 FOR NEAR INFINITY. A FLAT SURFACE IS 0 PERCENT, A 45 DEGREE SURFACE IS 100 PERCENT, AND AS THE SURFACE BECOMES MORE VERTICAL, THE PERCENT RISE BECOMES INCREASINGLY LARGER.

IF THE CENTER CELL IN THE IMMEDIATE NEIGHBORHOOD (3 X 3 WINDOW) IS NODATA, THE OUTPUT IS NODATA.

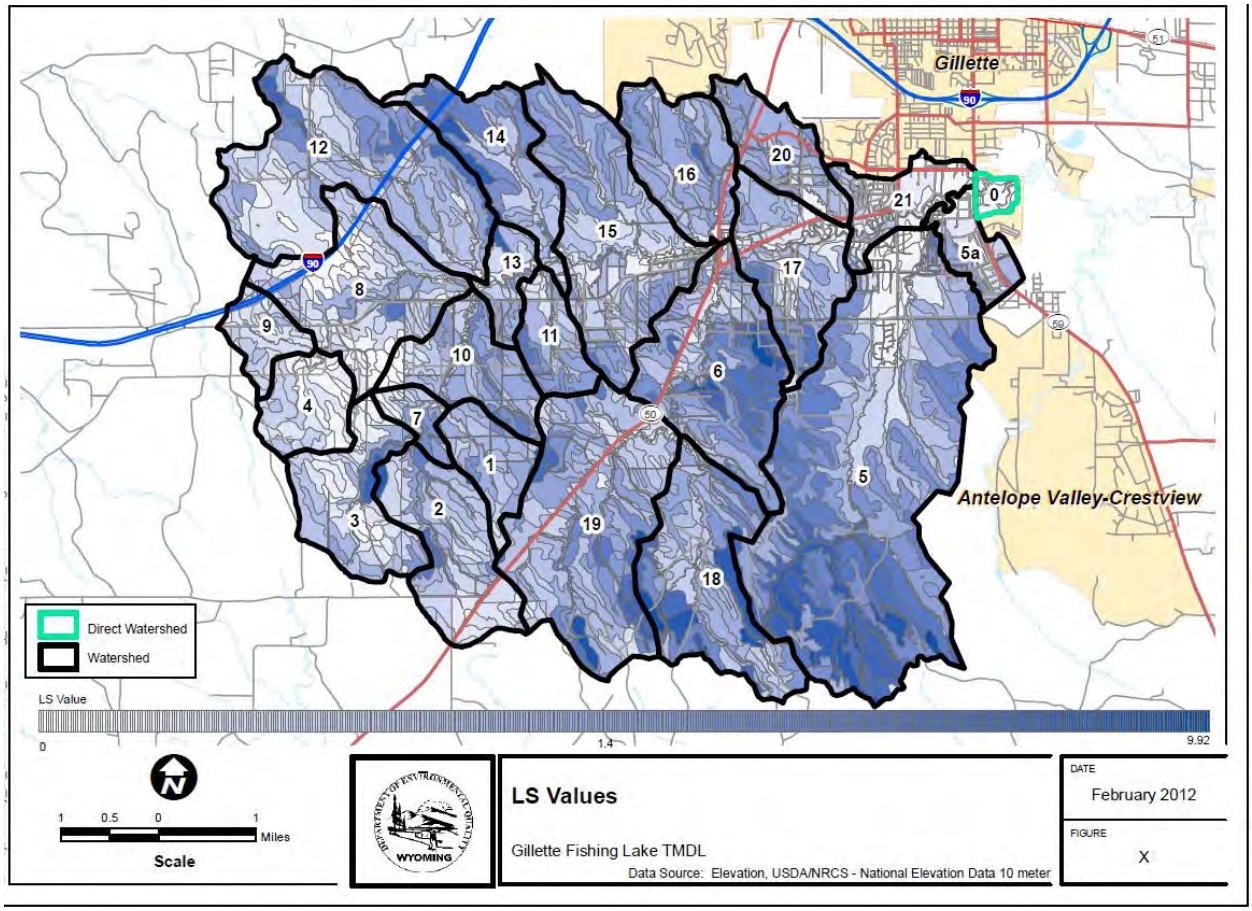
IF ANY NEIGHBORHOOD CELLS ARE NODATA, THEY ARE ASSIGNED THE VALUE OF THE CENTER CELL; THEN THE SLOPE IS COMPUTED.

Figure D-4 shows the results of applying the Slope function to the Gillette Fishing Lake watershed.



With the flow accumulation and slope calculated, the LS factor is calculated using the equation shown at the beginning of the LS section. Figure D-5 shows the results of the LS factor equation.

Figure D-5 – LS Factors



The LS factor coverage is then cut to subwatershed and land use. Table D-2 shows the area averaged LS factor per subwatershed per land use.

TABLE D-2 – LS FACTORS BY SUBBASIN AND BY LANDUSE

Subwatershed	Construction	Road	Rural Residential	Upland Shrub	Urban	Water	Wyoming Big Sage Brush
Direct Watershed	0.06	0.08	0.00	0.00	0.06	0.00	0.00
Subbasin 1	1.28	1.74	1.28	1.64	0.00	0.00	0.00
Subbasin 2	1.51	0.83	1.51	1.14	0.00	0.00	0.00
Subbasin 3	0.71	0.67	0.71	1.13	0.00	0.00	0.00
Subbasin 4	0.67	0.00	0.67	0.51	0.00	0.00	0.00
Subbasin 5	0.73	1.16	0.00	3.38	0.73	0.00	2.20
Subbasin 5a	0.84	0.95	0.00	0.00	0.84	0.00	1.86
Subbasin 6	1.30	1.43	1.30	0.00	1.07	0.00	1.91
Subbasin 7	0.93	0.63	0.93	1.54	0.00	0.00	0.00
Subbasin 8	0.80	0.55	0.80	0.53	0.98	0.00	0.77
Subbasin 9	0.85	0.67	0.00	0.64	0.85	0.00	0.00
Subbasin 10	1.24	1.26	1.24	2.17	0.00	0.00	0.10
Subbasin 11	1.53	1.72	1.53	0.00	1.43	0.00	0.77
Subbasin 12	1.49	1.32	0.00	1.49	0.00	0.00	1.22
Subbasin 13	1.49	1.22	1.49	0.00	0.00	0.00	1.11
Subbasin 14	1.03	0.92	1.03	1.82	0.00	0.00	1.81
Subbasin 15	1.28	0.99	1.30	0.00	1.26	0.00	0.94
Subbasin 16	1.66	1.20	0.10	0.00	1.66	0.00	1.35
Subbasin 17	0.95	1.22	0.95	0.00	0.70	0.00	1.63
Subbasin 18	2.11	1.41	0.00	2.43	0.00	0.00	2.11
Subbasin 19	1.29	1.20	1.29	1.85	0.00	0.00	1.55
Subbasin 20	1.37	1.49	1.11	0.00	1.37	0.00	1.51
Subbasin 21	0.76	1.07	0.00	0.00	0.76	0.00	0.78

C FACTOR

The C values for the Wyoming Big Sage Brush and Upland Shrub land uses were chosen from Table 10 of the USDA Handbook Number 537 (Wischmeier and Smith, 1978), reproduced below as Figure D-6. In discussions with Nephi Cole and Michelle Cook, it was suggested that the category for "Tall weeds or short brush with average drop fall height of 20 in" would provide the most appropriate C factors (Wyoming Association of Conservation Districts, January 13, 2012; Campbell County Conservation District, February 7, 2012). A value of 0.039 was chosen as the most appropriate value based on the discussions with Nephi Cole and Michelle Cook, and from the amount of vegetation seen in aerial photographs of the watershed.

FIGURE D-6 – FACTOR C FOR PERMANENT PASTURE, RANGE, AND IDLE LAND

TABLE 10.—*Factor* **C** *for permanent pasture, range, and idle land*[1]

Vegetative canopy		Cover that contacts the soil surface						
			Percent ground cover					
Type and height[2]	Percent cover[3]	Type[4]	0	20	40	60	80	95+
No appreciable canopy		G	0.45	0.20	0.10	0.042	0.013	0.003
		W	.45	.24	.15	.091	.043	.011
Tall weeds or short brush with average drop fall height of 20 in	25	G	.36	.17	.09	.038	.013	.003
		W	.36	.20	.13	.083	.041	.011
	50	G	.26	.13	.07	.035	.012	.003
		W	.26	.16	.11	.076	.039	.011
	75	G	.17	.10	.06	.032	.011	.003
		W	.17	.12	.09	.068	.038	.011
Appreciable brush or bushes, with average drop fall height of 6½ ft	25	G	.40	.18	.09	.040	.013	.003
		W	.40	.22	.14	.087	.042	.011
	50	G	.34	.16	.08	.038	.012	.003
		W	.34	.19	.13	.082	.041	.011
	75	G	.28	.14	.08	.036	.012	.003
		W	.28	.17	.12	.078	.040	.011
Trees, but no appreciable low brush. Average drop fall height of 13 ft	25	G	.42	.19	.10	.041	.013	.003
		W	.42	.23	.14	.089	.042	.011
	50	G	.39	.18	.09	.040	.013	.003
		W	.39	.21	.14	.087	.042	.011
	75	G	.36	.17	.09	.039	.012	.003
		W	.36	.20	.13	.084	.041	.011

[1] The listed **C** values assume that the vegetation and mulch are randomly distributed over the entire area.

[2] Canopy height is measured as the average fall height of water drops falling from the canopy to the ground. Canopy effect is inversely proportional to drop fall height and is negligible if fall height exceeds 33 ft.

[3] Portion of total-area surface that would be hidden from view by canopy in a vertical projection (a bird's-eye view).

[4] G: cover at surface is grass, grasslike plants, decaying compacted duff, or litter at least 2 in deep.

W: cover at surface is mostly broadleaf herbaceous plants (as weeds with little lateral-root network near the surface) or undecayed residues or both.

C factor values of 0.02 were used for the Urban, Rural Residential, and Road land uses. The values were obtained from course material used in University of Alabama soil erosion class. This source

was suggested to be used by Nephi Cole (Campbell County Conservation District, February 7, 2012). This C factor used for the urban land uses is similar to a 0.03 value used by Fernandez, et al. (2003). The C factor value for the construction land use areas was obtained from USEPA, which used a C factor value of 1 in a 2008 development document for proposed effluent guidelines for construction sites. In the USEPA document, USEPA states that the C factor was "Globally set to a value of 1.0 across all indicator cities and model projects. This value is for a denuded soil surface." (USEPA, November 21, 2008). C factors used in this analysis are presented in Table D-3 below.

TABLE D-3 – C FACTOR VALUES BY SUBBASIN AND BY LAND USE

Subwatershed	Construction	Road	Rural Residential	Upland Shrub	Urban	Water	Wyoming Big Sage Brush
Direct Watershed	1	0.02	0.02	0.039	0.02	0	0.039
Subbasin 1	1	0.02	0.02	0.039	0.02	0	0.039
Subbasin 2	1	0.02	0.02	0.039	0.02	0	0.039
Subbasin 3	1	0.02	0.02	0.039	0.02	0	0.039
Subbasin 4	1	0.02	0.02	0.039	0.02	0	0.039
Subbasin 5	1	0.02	0.02	0.039	0.02	0	0.039
Subbasin 5a	1	0.02	0.02	0.039	0.02	0	0.039
Subbasin 6	1	0.02	0.02	0.039	0.02	0	0.039
Subbasin 7	1	0.02	0.02	0.039	0.02	0	0.039
Subbasin 8	1	0.02	0.02	0.039	0.02	0	0.039
Subbasin 9	1	0.02	0.02	0.039	0.02	0	0.039
Subbasin 10	1	0.02	0.02	0.039	0.02	0	0.039
Subbasin 11	1	0.02	0.02	0.039	0.02	0	0.039
Subbasin 12	1	0.02	0.02	0.039	0.02	0	0.039
Subbasin 13	1	0.02	0.02	0.039	0.02	0	0.039
Subbasin 14	1	0.02	0.02	0.039	0.02	0	0.039
Subbasin 15	1	0.02	0.02	0.039	0.02	0	0.039
Subbasin 16	1	0.02	0.02	0.039	0.02	0	0.039
Subbasin 17	1	0.02	0.02	0.039	0.02	0	0.039
Subbasin 18	1	0.02	0.02	0.039	0.02	0	0.039
Subbasin 19	1	0.02	0.02	0.039	0.02	0	0.039
Subbasin 20	1	0.02	0.02	0.039	0.02	0	0.039
Subbasin 21	1	0.02	0.02	0.039	0.02	0	0.039

P FACTOR

Based on the interpretation of the P factor by Renard (1990, 1997), the P factor includes estimates of the effect of runoff reduction practices. In the Gillette Fishing Lake watershed, runoff is reduced and slowed because of the numerous small ponds throughout the watershed that detain water and trap sediment. As stated in the 205j report, "With the location of several man made dams on the creek, and the shallow gradient, sediment transport is minimal in its upper to mid reaches." Due to

this knowledge of the watershed, P values were used as adjusted factors to match collected in-lake sediment data.

Because these sediment traps hold sediment from all land uses, the same P factor was applied to all land uses in the watershed. In the watersheds that directly drains to the lake, there were no impoundments between the subbasin and Gillette Fishing Lake; therefore, for these areas, a P factor of 1 was used to represent to no hydraulic barriers for sediment transport. Table D-4 shows the P factors used in this analysis.

TABLE D-4 – P FACTORS BY SUBBASIN AND BY LAND USE

Subbasin	Construction	Road	Rural Residential	Upland Shrub	Urban	Water	Wyoming Big Sage Brush
Direct Watershed	1	1	1	1	1	0	1
Subbasin 1	0.3	0.3	0.3	0.31	0.3	0	0.3
Subbasin 2	0.3	0.3	0.3	0.31	0.3	0	0.3
Subbasin 3	0.3	0.3	0.3	0.31	0.3	0	0.3
Subbasin 4	0.3	0.3	0.3	0.31	0.3	0	0.3
Subbasin 5	0.3	0.3	0.3	0.31	0.3	0	0.3
Subbasin 5a	1	1	1	1	1	0	1
Subbasin 6	0.3	0.3	0.3	0.31	0.3	0	0.3
Subbasin 7	0.3	0.3	0.3	0.31	0.3	0	0.3
Subbasin 8	0.3	0.3	0.3	0.31	0.3	0	0.3
Subbasin 9	0.3	0.3	0.3	0.31	0.3	0	0.3
Subbasin 10	0.3	0.3	0.3	0.31	0.3	0	0.3
Subbasin 11	0.3	0.3	0.3	0.31	0.3	0	0.3
Subbasin 12	0.3	0.3	0.3	0.31	0.3	0	0.3
Subbasin 13	0.3	0.3	0.3	0.31	0.3	0	0.3
Subbasin 14	0.3	0.3	0.3	0.31	0.3	0	0.3
Subbasin 15	0.3	0.3	0.3	0.31	0.3	0	0.3
Subbasin 16	0.3	0.3	0.3	0.31	0.3	0	0.3
Subbasin 17	0.3	0.3	0.3	0.31	0.3	0	0.3
Subbasin 18	0.3	0.3	0.3	0.31	0.3	0	0.3
Subbasin 19	0.3	0.3	0.3	0.31	0.3	0	0.3
Subbasin 20	0.3	0.3	0.3	0.31	0.3	0	0.3
Subbasin 21	1	1	1	1	1	0	1

SEDIMENT DELIVERY RATIO

The sediment delivery ratio values for each subbasin were obtained from equations provided in the EPA STEPL model (EPA, 2010). The EPA STEPL model calculates the SDR using the following equation for watersheds larger than 200 acres:

SDR=0.417662A^-0.134958 - 0.127097, where A is the area of the watershed in acres.

For the SDR calculation, the Gillette Fishing Lake watershed was divided into three areas.

- The first area contains the subbasins, Direct Watershed, 5a, 17, 20, and 21, which are directly hydrologically connected to Gillette Fishing Lake. In these subbasins, an SDR of 1 was used to represent that fact that these watersheds were adjacent and connected to Gillette Fishing Lake, therefore very little impede occurs for sediment delivery.
- The second area was subbasin 5. Subbasin 5 was considered on its own due to several factors: large size, direct link to subbasin 5a, which drains almost directly into the lake, and that fact that it does not interact with other subbasins. Using the STEPL SDR equation for Subbasin 5, the SDR is calculated to be 0.19.
- The remaining subbasins form a third area that can be considered one entire watershed. The STEPL equation for the remaining subbasins calculates the SDR to be 0.13. Table D-5 shows the SDR values used in the analysis.

TABLE D-5 – SEDIMENT DELIVERY RATIOS BY SUBBASIN

Subwatershed	Sediment Delivery Ratio
Direct Watershed	1
Subbasin 1	0.13
Subbasin 2	0.13
Subbasin 3	0.13
Subbasin 4	0.13
Subbasin 5	0.19
Subbasin 5a	1
Subbasin 6	0.13
Subbasin 7	0.13
Subbasin 8	0.13
Subbasin 9	0.13
Subbasin 10	0.13
Subbasin 11	0.13
Subbasin 12	0.13
Subbasin 13	0.13
Subbasin 14	0.13
Subbasin 15	0.13
Subbasin 16	0.13
Subbasin 17	1
Subbasin 18	0.13
Subbasin 19	0.13
Subbasin 20	1
Subbasin 21	1

CONSTRUCTION AREAS

During the last 25 years, a considerable amount of construction activity has occurred within the watershed. No exact construction areas were available (City of Gillette, January 23, 2012). Therefore, to estimate the number of acres under construction per year, the City's subdivision GIS data was used. In the City of Gillette and in Campbell County, construction usually only occurs if an area has been designated a subdivision. Within each subdivision, developers can construct residential areas, commercial areas, or any type of mixed use. Figures D-7A and 7B, below shows the City's subdivision GIS layer, along with the area, in acres, of each subdivision and the year in which the subdivision was platted. Only the subdivisions platted between the years 1985 (the year the lake was last dredged) to 2007 (the year before the sediment in the lake was measured) were used. These were the years that contributed to the sediment that was measured in the lake in 2008. Table D-6 shows the total area in each subbasin that was considered to be under construction each year.

Figure D-7A – Subdivision

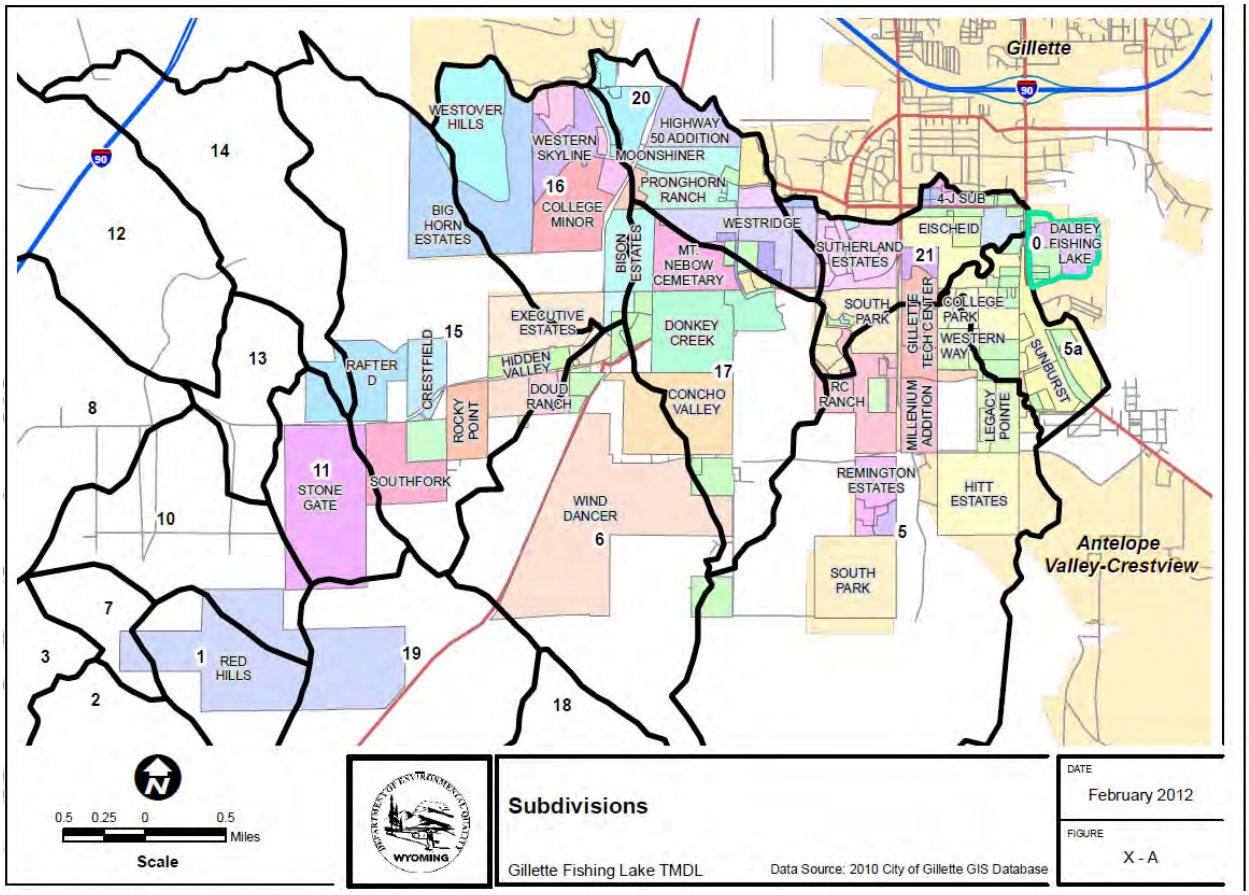


Figure D-7B – Subdivision Legend

Subdivision Name	Year	Acres
WESTRIDGE SUB FIRST EXT	1985	60.52
FREUND SUBDIVISION	1986	2.87
WILLAMETTE MANOR MH SUBDIVISION	1987	18.14
SKYLINE SUBDIVISION	1988	15.72
SOUTH PARK SUBDIVISION PI	1988	91
EXECUTIVE ESTATES	1989	161.52
O.N.O. SUBD	1990	6.26
WESTOVER HILLS PIII	1991	5.92
ESQUIRE ESTATES PI	1992	1.43
PRONGHORN SCHOOL SITE	1992	14.52
STONE GATE ESTATES PI	1992	324.7
WIND DANCER II SUBDIVISION	1993	541.34
CAMBRIA I	1994	3.86
SAYLER ADDITION	1994	3
SUNBURST W & S DISTRICT	1994	5.91
THE BLUFFS SUBDIVISION F3 PI	1994	2.62
CAMBRIA II ADDITION	1995	3.07
CAMBRIA III ADDITION	1995	17.9
DOUD RANCH ADDITION PI	1995	13.94
ESQUIRE ESTATES PIV	1995	3.55
EXECUTIVE ESTATES PII	1995	14.07
SEYMOUR SUBDIVISION	1995	4.98
SOUTHERN DRIVE SUBDIVISION	1995	34.28
BISON ESTATES TRACT 1	1996	59.96
BISON ESTATES TRACT 2	1996	5.45
BISON ESTATES TRACT 3	1996	97.4
ESQUIRE ESTATES PV	1996	1.7
RAFTER D SUBDIVISION	1996	161.68
SOUTH PARK SUBDIVISION PII F1	1996	17.89
DEER PARK SUBDIVISION	1997	6.46
ESQUIRE ESTATES PVI	1997	2.69
STEWART BUSINESS PARK	1998	1
THE BLUFFS SUBDIVISION F3 PII	1998	2.1
MARKET SQUARE PLAZA	1999	31.64
TOWNE & COUNTRY EST PI	1999	6.19
TOWNE & COUNTRY EST PII	1999	7.18
CITY OF GILLETTE MILLENIUM ANNEXATION	2000	66.22
CITY OF GILLETTE MILLENNIUM ANNEXATION	2000	23.96
REDING WOOD SUBDIVISION	2000	20
SUTHERLAND COVE	2000	3.93
HIDDEN VALLEY WATER TANK ANNEXATION	2001	2.99
MAHER SUBDIVISION	2001	9.99

Subdivision Name	Year	Acres
PROMONTORY PARK	2001	9.39
CREEKSIDE SUBDIVISION	2002	3.5
FREUND SUBDIVISION PII	2002	2.02
MOONSHINER ESTATES	2002	16.22
WESTERN WAY PI	2002	9.94
DOUD RANCH ADDITION PII	2003	7.39
GILLETTE TECH CENTER	2003	47.86
PATRIOT ESTATES	2003	18.95
SCHLAUTMANN SUBDIVISION	2003	3.38
SOUTH PARK VILLAS PI	2003	3.05
BIG HORN ESTATES	2004	318.36
HIGHWAY 50 ADDITION	2004	90.13
MOONSHINER ESTATES II	2004	61.28
PROMONTORY PARK II ANNEXATION	2004	16.29
SOUTH PARK SUBDIVISION PIII F1	2004	11.78
SOUTH PARK SUBDIVISION PIII F2	2004	5.45
SOUTH PARK VILLAS PII	2004	3.07
WIND DANCER II SUBDIVISION	2004	38.03
CASTLE HEIGHTS ESTATES PI	2005	27.11
MELGAARD INDUSTRIAL	2005	6.13
SUNBURST ESTATES PI	2005	8.55
SUNBURST ESTATES PII	2005	3.89
CELESTIAL ESTATES PI	2006	20.13
COLLEGE PARK ADDITION PI	2006	15.07
CRESTFIELD SUBDIVISION	2006	60.77
DOUD RANCH ADDITION PIII	2006	20.16
EVANGELICAL CHURCH SUBDIVISION	2006	20
NORTHERN PRODUCTION ADDITION	2006	5.39
RC RANCH PI	2006	86.94
REMINGTON ESTATES PII	2006	47.58
SUNBURST SUBDIVISION PIII	2006	2.14
WESTERN SKY SUBDIVISION PI	2006	9.29
WESTERN SKYLINE ADDITION	2006	94.11
WESTERN WAY PII	2006	34.83
COLLEGE PARK PII	2007	25.62
GILLETTE TECH CENTER PII	2007	27.51
PRONGHORN RANCH PI	2007	73.21
RC RANCH PII	2007	37.04
WESTERN SKY SUBDIVISION PII	2007	5.77
WESTERN SKY SUBDIVISION PIII	2007	30.13
COLLEGE MINOR SUBDIVISION	2008	136.55
CRESTFIELD PII	2008	6.64

Subdivision Name	Year	Acres
CRESTFIELD PII	2008	6.64
EISCHEID SUBDIVISION	2008	20.4
QWEST SUBDIVISION	2008	3.2
RC RANCH BUSINESS PARK I	2008	3.54
RED HILLS SUBDIVISION	2008	559.89
SOUTH FORK PUD	2008	15.45
ANTELOPE RIDGE SUBDIVISION	2009	19.63
EMS	2009	6.38
PRONGHORN RANCH PI, RESUB OF BLOCK 2 LOTS 27-34	2009	0.68
REMINGTON ESTATES PIV F1	2009	8.78
STOCKTRAIL SUBDIVISION, LOTS 1A AND 1B	2009	0.84
LEGACY POINTE	2010	18.46
LOTS 13A-17A SOUTH PARK VILLAS, PII	2010	1.1
MOUNT NEBOW CEMETARY	2010	104.64
REMINGTON ESTATES PIII F1	2010	3.51
RESUB BLOCK 4 RC RANCH P 1	2010	6.73
RESUB LOT 34 BLOCK 2 RC RANCH P I	2010	3.29
RESUB. LOTS 2A & 2B SUNBURST SUBD. NO.4	2010	38.74
VILLAS AT LEGACY RIDGE	2010	9.81
REMINGTON ESTATES P III, F 2	2011	13.64
REMINGTON ESTATES PIV F2	2011	5.49
Resub Lots 17-22, Block 2 of Pronghorn Ranch Ph 1	2011	1
Resub. Tract B, Gillette Tech Center, Phase II	2011	17.3
TRACTS B1 AND B2 LEGACY POINTE	2011	55.94

Subdivisions - Legend

Gillette Fishing Lake TMDL

Data Source: 2010 City of Gillette GIS Database

DATE: February 2012

FIGURE: X - B

TABLE D-6 – CONSTRUCTION AREA BY YEAR AND BY SUBBASIN

Amount of area, in acres, under construction, from Subdivision data, between the years 1985 and 2007														
Year / Subbasins	Direct Watershed	10	11	13	14	15	16	17	19	20	21	5	5a	6
1985								0		58	2			
1986	3													
1987												2	16	
1988										1	55	36		16
1989						95	56							11
1990													6	
1991							1			5				
1992		17	288			9		3	10	12	1			
1993								19	3					519
1994										6	3	4	2	
1995						21	0	35		17	4		5	10
1996			37	0.1	34	91	51	50		66	16			
1997								3		3	3			
1998										2	1		0	
1999								12		1	31		1	
2000											28	66	20	
2001						2		10					9	1
2002	2						12			4		7	6	
2003						7	14	4			30	21	3	1
2004						195	164			149	20		16	
2005										27			19	
2006						67	123			20	11	167	14	14
2007							36	10		73	3	61	15	
Total Area under construction for all 23 years (Acres)	5	17	325	0	34	487	457	147	13	444	208	364	134	572
Average Area under construction per year (Acres)	0.2	0.8	14.1	0.0	1.5	21.2	19.8	6.4	0.5	19.3	9.1	15.8	5.8	24.9

TABLE D-7 – LAND USE BY SUBBASIN

Land Use	Construction		Road		Rural Residential		Upland Shrub		Urban		Water		Wyoming Big Sage Brush		
Subbasins	**Area (Acres)**	**Area**	**Area (Acres)**	**Area**	**Area (Acres)**	**Area**	**Area)**	**Area**	**Area (Acres)**	**Area**	**Area (Acres)**	**Area**	**Area (Acres)**	**Area**	**Total Sum of Area (Acres)**
Direct Watershed	0.21	0.21%	2.04	2.1%	0.00	0.0%	0.00	0.0%	79.09	79.6%	18.07	18.2%	0.00	0.0%	99.41
Subbasin 1	0.00	0.00%	10.16	2.1%	0.33	0.1%	476.50	97.0%	0.00	0.0%	4.05	0.8%	0.00	0.0%	491.05
Subbasin 2	0.00	0.00%	9.34	0.9%	285.86	26.1%	789.35	71.9%	0.00	0.0%	12.75	1.2%	0.00	0.0%	1097.30
Subbasin 3	0.00	0.00%	4.61	0.5%	144.14	15.1%	796.24	83.3%	0.00	0.0%	11.36	1.2%	0.00	0.0%	956.36
Subbasin 4	0.00	0.00%	0.00	0.0%	0.52	0.1%	549.78	98.5%	0.00	0.0%	7.77	1.4%	0.00	0.0%	558.07
Subbasin 5	15.85	0.32%	60.34	1.2%	0.00	0.0%	45.90	0.9%	344.25	7.0%	50.16	1.0%	4427.88	89.6%	4944.39
Subbasin 5a	5.81	1.56%	47.42	12.7%	0.00	0.0%	0.00	0.0%	266.09	71.5%	3.25	0.9%	49.83	13.4%	372.40
Subbasin 6	24.89	1.55%	40.14	2.5%	399.51	24.9%	0.00	0.0%	16.01	1.0%	21.79	1.4%	1103.29	68.7%	1605.64
Subbasin 7	0.00	0.00%	2.19	1.0%	84.81	39.0%	126.41	58.1%	0.00	0.0%	4.18	1.9%	0.00	0.0%	217.59
Subbasin 8	0.00	0.00%	33.06	2.3%	374.46	26.3%	556.57	39.1%	78.65	5.5%	23.99	1.7%	355.16	25.0%	1421.89
Subbasin 9	0.00	0.00%	9.90	2.8%	0.00	0.0%	249.88	71.2%	87.51	24.9%	3.91	1.1%	0.00	0.0%	351.20
Subbasin 10	0.75	0.09%	17.76	2.2%	649.85	81.5%	118.11	14.8%	0.00	0.0%	10.61	1.3%	0.10	0.0%	797.17
Subbasin 11	14.13	3.13%	10.22	2.3%	410.30	91.0%	0.00	0.0%	8.65	1.9%	4.73	1.0%	2.94	0.7%	450.98
Subbasin 12	0.00	0.00%	14.79	0.6%	0.00	0.0%	1603.66	67.3%	0.00	0.0%	28.00	1.2%	737.34	30.9%	2383.79
Subbasin 13	0.01	0.00%	4.33	1.4%	126.36	39.6%	0.00	0.0%	0.00	0.0%	10.83	3.4%	177.47	55.6%	318.99
Subbasin 14	1.48	0.16%	6.35	0.7%	25.14	2.7%	112.29	12.1%	0.00	0.0%	12.03	1.3%	769.04	83.0%	926.33
Subbasin 15	21.17	1.16%	41.36	2.3%	246.54	13.6%	0.00	0.0%	339.89	18.7%	28.09	1.5%	1141.38	62.8%	1818.43
Subbasin 16	19.85	2.19%	17.36	1.9%	5.00	0.6%	0.00	0.0%	208.67	23.0%	15.52	1.7%	641.51	70.7%	907.91
Subbasin 17	6.39	0.64%	33.99	3.4%	460.69	45.9%	0.00	0.0%	41.73	4.2%	15.28	1.5%	446.25	44.4%	1004.33
Subbasin 18	0.00	0.00%	10.68	0.7%	0.00	0.0%	127.90	8.4%	0.00	0.0%	24.81	1.6%	1365.99	89.3%	1529.39
Subbasin 19	0.55	0.02%	26.05	1.1%	237.56	10.2%	1294.45	55.6%	0.00	0.0%	37.85	1.6%	730.03	31.4%	2326.49
Subbasin 20	19.29	3.13%	34.75	5.6%	2.65	0.4%	0.00	0.0%	310.91	50.5%	7.25	1.2%	240.76	39.1%	615.62
Subbasin 21	9.06	1.73%	55.23	10.6%	0.00	0.0%	0.00	0.0%	442.42	84.7%	12.68	2.4%	2.82	0.5%	522.20
Grand Total	139.44	15.91%	492.07	60.8%	3453.75	416.9%	6847.04	678.3%	2223.89	372.4%	368.97	50.6%	12191.79	705.1%	25716.95

In order to incorporate the areas under construction into the land use categories, area was taken out of either the Urban land use or the Rural Residential land use so the total area of the subbasin remained the same. Table D-7 shows the final areas used in the watershed calculations by subbasin and by land use.

SOIL PHOSPHORUS

As part of the sampling regime to collect data for use in this TMDL, three soil samples were collected at the inlet of Gillette Fishing Lake and the soil phosphorus concentration was measured. The TP soil concentration for the three samples was measured at 220, 369, and 104 mg/kg. The average of these three samples is approximately 230 mg/kg.

At the request of the WDEQ, additional research was conducted to determine if any soil TP concentrations had been taken in other locations throughout the watershed. The research yielded a report that noted 23 soil samples, specifically TP concentrations, were taken throughout Campbell County (see Table D-8). The specific locations of these samples were not specified and coordination with the source, NRCS, of this information was not able to provide the locations (NRCS, 2012). From the NRCS data, the top layer of soil measured an average of 274 mg/kg of TP. The next layer down, ranging from 2 to 10 inches deep, averaged 224 mg/kg of TP. The average of the two top layers was 250 mg/kg. The value noted by the NRCS was similar to the samples collected at the inlet of Gillette Fishing Lake. It was determine that the NRCS values would be utilized for particulate TP calculations in order to have a value that was collected at a more regional basis. Therefore, the average value of the soil TP, 250 mg/kg by the NRCS was utilized.

TABLE D-8 – NRCS SOIL PHOSPHORUS DATA

S09WY0051051		S09WY0051056		S09WY0051058		S09WY0051059		S09WY0051060	
Depth (in)	**TP Phosphorus (mg/kg)**	**Depth (in)**	**TP Phosphorus (mg/kg)**	**Depth (in)**	**TP Phosphorus (mg/kg)**	**Depth (in)**	**TP Phosphorus (mg/kg)**	**Depth (in)**	**TP Phosphorus (mg/kg)**
0-2	518.9	0-2	258.3	0-2	129.8	0-2	281.1	0-2	162.3
2-6	419.9	2-4	177.5	2-8	93.4	2-7	215	2-4	141.1
6-21	607.3	4-18	125.1	8-23	77.6	7-28	175.4	4-17	143.5
21-36	506.8	18-27	124.3	23-35	54.8	28-40	162.8	17-40	186.6
36-40	212.4	27-40	159.9	35-40	70.2				
S09WY0051067		**S09WY0051073**		**S09WY0051074**		**S09WY0051075**		**S09WY0051101**	
Depth (in)	**TP Phosphorus (mg/kg)**	**Depth (in)**	**TP Phosphorus (mg/kg)**	**Depth (in)**	**TP Phosphorus (mg/kg)**	**Depth (in)**	**TP Phosphorus (mg/kg)**	**Depth (in)**	**TP Phosphorus (mg/kg)**
0-2	169.8	0-2	127.7	0-2	522.4	0-2	446.8	0-2	420.9
2-5	144.4	2-7	89.6	2-7	479.2	2-7	355.7	2-5	305.6
5-13	152.9	7-16	130.7	7-14	417.8	7-23	314.8	5-23	266
13-22	152.5	16-42	129	14-40	312.9	23-40	276.1	23-32	265.7
22-40	135.9								
S09WY0051105		**S09WY0051106**		**S09WY0051110**		**S09WY0051112**		**S09WY0551076**	
Depth (in)	**TP Phosphorus (mg/kg)**	**Depth (in)**	**TP Phosphorus (mg/kg)**	**Depth (in)**	**TP Phosphorus (mg/kg)**	**Depth (in)**	**TP Phosphorus (mg/kg)**	**Depth (in)**	**TP Phosphorus (mg/kg)**
0-2	140.9	0-2	254.6	0-2	230.2	0-2	214	0-2	195.4
2-20	208.2	2-19	215.7	2-18	208.4	2-4	228.5	2-6	42.3
33-40	210.1	19-40	185.2	18-28	349.8	4-26	253.1	6-20	108.1
46	363.8					26-40	230.6	20-40	71.6

S09WY0551079		S09WY0551081		S09WY0551091		S09WY0551093		S09WY0551095	
Depth (in)	**TP Phosphorus (mg/kg)**	**Depth (in)**	**TP Phosphorus (mg/kg)**	**Depth (in)**	**TP Phosphorus (mg/kg)**	**Depth (in)**	**TP Phosphorus (mg/kg)**	**Depth (in)**	**TP Phosphorus (mg/kg)**
0-2	233.8	0-2	190	0-2	335.7	0-2	264.2	0-2	235.4
2-9	89.9	2-5	127.5	2-4	363.5	2-8	177.7	2-8	170.5
9-25	69.9	5-11	118.5	4-22	402.5	8-18	30.9	8-20	245.6
25-51	93.3	11-41	176.8	22-40	395.7			20-30	294.6
								30-40	300
S09WY0551096		**S09WY0551097**		**S09WY0551098**					
Depth (in)	**TP Phosphorus (mg/kg)**	**Depth (in)**	**TP Phosphorus (mg/kg)**	**Depth (in)**	**TP Phosphorus (mg/kg)**	**Depth**	**Average TP Phosphorus (mg/kg)**	**Average TP Phosphorus (mg/kg) for Depth Ranges 1 & 2**	
0-2	160.6	0-2	415.5	0-2	397.1	Range 1	274.1	249.1	
2-6	179.7	2-4	421.2	2-10	297.5	Range 2	224.0		
6-18	195.4	4-20	284.7	10-28	270.6				
18-30	258.9	20-30	337.4	28-40	263.6				
30-40	234.3	30-40	246.2						

FINAL RUSLE ESTIMATE

All the factors used in the RUSLE equation, for each subbasin, for each land use have been explained and presented above, and the following are the results of the RUSLE sediment load calculations:

- Table D-9 shows the gross sediment loading (sediment loading before applying the SDR) per acre by subbasin and land use.
- Table D-10 shows the same values by land use type only.
- Table D-11 shows the gross sediment loading by land use and by subbasin after the RUSLE factors have been multiplied by the area of land use within the subbasin.
- Table D-12 shows the gross sediment load by land use only.
- Table D-13 shows the final sediment loading by land use and subbasin.
- Table D-14 shows the final sediment loading by land use only.
- Table D-15 shows the particulate phosphorus load by subbasin and by land use, which was calculated by multiplying the final sediment load, derived using RUSLE, by the soil phosphorus concentration, from the NRCS data, and appropriate unit conversion.
- Table D-16 shows the particulate phosphorus loading by land use only.

TABLE D-9 – RUSLE GROSS SEDIMENT LOAD BY SUBBASIN AND BY LAND USE PER ACRE

	Gross Sediment Load (Tons / Acre / Year)							
Subbasin / Landuse	Construction	Road	Rural Residential	Upland Shrub	Urban	Water	Wyoming Big Sage Brush	Total
Direct Watershed	0.62	0.02	0.00	0.00	0.01	0.00	0.00	0.65
Subbasin 1	4.06	0.10	0.08	0.18	0.00	0.00	0.00	4.43
Subbasin 2	4.75	0.05	0.10	0.14	0.00	0.00	0.00	5.03
Subbasin 3	2.26	0.04	0.05	0.15	0.00	0.00	0.00	2.50
Subbasin 4	2.37	0.00	0.05	0.07	0.00	0.00	0.00	2.49
Subbasin 5	2.21	0.07	0.00	0.42	0.04	0.00	0.27	3.01
Subbasin 5a	7.63	0.17	0.00	0.00	0.15	0.00	0.65	8.60
Subbasin 6	4.28	0.09	0.09	0.00	0.07	0.00	0.23	4.76
Subbasin 7	3.02	0.04	0.06	0.19	0.00	0.00	0.00	3.32
Subbasin 8	2.65	0.04	0.05	0.07	0.06	0.00	0.10	2.97
Subbasin 9	2.77	0.04	0.00	0.08	0.06	0.00	0.00	2.95
Subbasin 10	3.95	0.08	0.08	0.25	0.00	0.00	0.01	4.36
Subbasin 11	4.68	0.10	0.09	0.00	0.08	0.00	0.08	5.04
Subbasin 12	4.81	0.08	0.00	0.19	0.00	0.00	0.15	5.23
Subbasin 13	4.59	0.08	0.09	0.00	0.00	0.00	0.14	4.90
Subbasin 14	2.66	0.06	0.05	0.23	0.00	0.00	0.23	3.23
Subbasin 15	4.19	0.07	0.08	0.00	0.08	0.00	0.12	4.54
Subbasin 16	5.52	0.08	0.01	0.00	0.11	0.00	0.17	5.89
Subbasin 17	3.10	0.08	0.06	0.00	0.04	0.00	0.21	3.48
Subbasin 18	6.74	0.09	0.00	0.31	0.00	0.00	0.26	7.40
Subbasin 19	4.14	0.08	0.08	0.23	0.00	0.00	0.19	4.72
Subbasin 20	4.61	0.10	0.07	0.00	0.09	0.00	0.21	5.09
Subbasin 21	7.86	0.23	0.00	0.00	0.16	0.00	0.29	8.54
Total	93.48	1.78	1.09	2.49	0.97	0.00	3.32	103.13

TABLE D-10 – RUSLE GROSS SEDIMENT LOAD BY LAND USE PER ACRE

Land Use	Gross Sediment Load (Tons / Acre / Year)
Construction	93.48
Road	1.78
Rural Residential	1.09
Upland Shrub	2.49
Urban	0.97
Water	0.00
Wyoming Big Sage Brush	3.32

TABLE D-11 – RUSLE GROSS SEDIMENT LOAD BY SUBBASIN AND BY LAND USE

	Gross Sediment Load (Tons / Year)							
Subbasin / Landuse	**Construction**	**Road**	**Rural Residential**	**Upland Shrub**	**Urban**	**Water**	**Wyoming Big Sage Brush**	**Total**
Direct Watershed	0.1	0.0	0.0	0.0	1.0	0.0	0.0	1.1
Subbasin 1	0.0	1.0	0.0	87.9	0.0	0.0	0.0	88.9
Subbasin 2	0.0	0.5	27.2	107.0	0.0	0.0	0.0	134.6
Subbasin 3	0.0	0.2	6.5	115.7	0.0	0.0	0.0	122.4
Subbasin 4	0.0	0.0	0.0	38.4	0.0	0.0	0.0	38.4
Subbasin 5	35.0	4.3	0.0	19.2	15.2	0.0	1206.0	1279.6
Subbasin 5a	44.3	8.2	0.0	0.0	40.6	0.0	32.4	125.4
Subbasin 6	106.5	3.8	34.2	0.0	1.1	0.0	256.8	402.5
Subbasin 7	0.0	0.1	5.1	24.0	0.0	0.0	0.0	29.3
Subbasin 8	0.0	1.2	19.9	37.9	5.0	0.0	34.2	98.2
Subbasin 9	0.0	0.4	0.0	20.7	4.8	0.0	0.0	25.9
Subbasin 10	3.0	1.4	51.3	29.1	0.0	0.0	0.0	84.8
Subbasin 11	66.2	1.1	38.4	0.0	0.7	0.0	0.2	106.6

	Gross Sediment Load (Tons / Year)							
Subbasin / Landuse	**Construction**	**Road**	**Rural Residential**	**Upland Shrub**	**Urban**	**Water**	**Wyoming Big Sage Brush**	**Total**
Subbasin 12	0.0	1.3	0.0	300.5	0.0	0.0	113.9	415.7
Subbasin 13	0.0	0.3	11.6	0.0	0.0	0.0	24.7	36.7
Subbasin 14	4.0	0.4	1.3	25.8	0.0	0.0	174.5	205.9
Subbasin 15	88.8	2.7	20.9	0.0	28.2	0.0	135.3	275.9
Subbasin 16	109.5	1.4	0.0	0.0	23.0	0.0	111.6	245.5
Subbasin 17	19.8	2.6	28.5	0.0	1.8	0.0	91.8	144.6
Subbasin 18	0.0	1.0	0.0	39.3	0.0	0.0	359.2	399.4
Subbasin 19	2.3	2.0	19.7	291.6	0.0	0.0	137.9	453.4
Subbasin 20	89.0	3.5	0.2	0.0	28.7	0.0	51.3	172.6
Subbasin 21	71.2	12.4	0.0	0.0	69.6	0.0	0.8	154.0
Total	639.5	49.7	264.9	1137.0	219.7	0.0	2730.6	5041.5

TABLE D-12 – RUSLE GROSS SEDIMENT LOAD BY LAND USE

Land Use	Gross Sediment Load (Tons / Year)
Construction	639.5
Road	49.7
Rural Residential	264.9
Upland Shrub	1137.0
Urban	219.7
Water	0.0
Wyoming Big Sage Brush	2730.6
Grand Total	5041.5

TABLE D-13 – RUSLE SEDIMENT LOAD BY SUBBASIN AND BY LAND USE

	Sediment Load (Tons / Year)							
Subbasins / Land Use	**Construction**	**Road**	**Rural Residential**	**Upland Shrub**	**Urban**	**Water**	**Wyoming Big Sage Brush**	**Total**
Direct Watershed	0.1	0.0	0.0	0.0	1.0	0.0	0.0	1.1
Subbasin 1	0.0	0.1	0.0	11.4	0.0	0.0	0.0	11.6
Subbasin 2	0.0	0.1	3.5	13.9	0.0	0.0	0.0	17.5
Subbasin 3	0.0	0.0	0.8	15.0	0.0	0.0	0.0	15.9
Subbasin 4	0.0	0.0	0.0	5.0	0.0	0.0	0.0	5.0
Subbasin 5	6.6	0.8	0.0	3.6	2.9	0.0	229.1	243.1
Subbasin 5a	44.3	8.2	0.0	0.0	40.6	0.0	32.4	125.4
Subbasin 6	13.8	0.5	4.4	0.0	0.1	0.0	33.4	52.3
Subbasin 7	0.0	0.0	0.7	3.1	0.0	0.0	0.0	3.8
Subbasin 8	0.0	0.2	2.6	4.9	0.6	0.0	4.4	12.8
Subbasin 9	0.0	0.1	0.0	2.7	0.6	0.0	0.0	3.4
Subbasin 10	0.4	0.2	6.7	3.8	0.0	0.0	0.0	11.0
Subbasin 11	8.6	0.1	5.0	0.0	0.1	0.0	0.0	13.9
Subbasin 12	0.0	0.2	0.0	39.1	0.0	0.0	14.8	54.0
Subbasin 13	0.0	0.0	1.5	0.0	0.0	0.0	3.2	4.8
Subbasin 14	0.5	0.0	0.2	3.4	0.0	0.0	22.7	26.8
Subbasin 15	11.5	0.4	2.7	0.0	3.7	0.0	17.6	35.9
Subbasin 16	14.2	0.2	0.0	0.0	3.0	0.0	14.5	31.9
Subbasin 17	19.8	2.6	28.5	0.0	1.8	0.0	91.8	144.6
Subbasin 18	0.0	0.1	0.0	5.1	0.0	0.0	46.7	51.9
Subbasin 19	0.3	0.3	2.6	37.9	0.0	0.0	17.9	58.9
Subbasin 20	89.0	3.5	0.2	0.0	28.7	0.0	51.3	172.6
Subbasin 21	71.2	12.4	0.0	0.0	69.6	0.0	0.8	154.0
Total	280.4	30.1	59.4	149.0	152.7	0.0	580.7	1252.2

TABLE D-14 – RUSLE SEDIMENT LOAD BY LAND USE

Land Use	Sediment Load (Tons / Year)
Construction	280.4
Road	30.1
Rural Residential	59.4
Upland Shrub	149.0
Urban	152.7
Water	0.0
Wyoming Big Sage Brush	580.7
Grand Total	1252.2

TABLE D-15 – PARTICULATE PHOSPHORUS LOAD BY SUBBASIN AND BY LAND USE

	Particulate Phosphorus Load (lbs/year)							
Subbasins / Land Use	**Construction**	**Road**	**Rural Residential**	**Upland Shrub**	**Urban**	**Water**	**Wyoming Big Sage Brush**	**Total**
Direct Watershed	0.1	0.0	0.0	0.0	0.5	0.0	0.0	0.6
Subbasin 1	0.0	0.1	0.0	5.7	0.0	0.0	0.0	5.8
Subbasin 2	0.0	0.0	1.8	7.0	0.0	0.0	0.0	8.7
Subbasin 3	0.0	0.0	0.4	7.5	0.0	0.0	0.0	8.0
Subbasin 4	0.0	0.0	0.0	2.5	0.0	0.0	0.0	2.5
Subbasin 5	3.3	0.4	0.0	1.8	1.4	0.0	114.6	121.6
Subbasin 5a	22.1	4.1	0.0	0.0	20.3	0.0	16.2	62.7
Subbasin 6	6.9	0.2	2.2	0.0	0.1	0.0	16.7	26.2
Subbasin 7	0.0	0.0	0.3	1.6	0.0	0.0	0.0	1.9
Subbasin 8	0.0	0.1	1.3	2.5	0.3	0.0	2.2	6.4
Subbasin 9	0.0	0.0	0.0	1.3	0.3	0.0	0.0	1.7
Subbasin 10	0.2	0.1	3.3	1.9	0.0	0.0	0.0	5.5

	Particulate Phosphorus Load (lbs/year)							
Subbasins / Land Use	**Construction**	**Road**	**Rural Residential**	**Upland Shrub**	**Urban**	**Water**	**Wyoming Big Sage Brush**	**Total**
Subbasin 11	4.3	0.1	2.5	0.0	0.0	0.0	0.0	6.9
Subbasin 12	0.0	0.1	0.0	19.5	0.0	0.0	7.4	27.0
Subbasin 13	0.0	0.0	0.8	0.0	0.0	0.0	1.6	2.4
Subbasin 14	0.3	0.0	0.1	1.7	0.0	0.0	11.3	13.4
Subbasin 15	5.8	0.2	1.4	0.0	1.8	0.0	8.8	17.9
Subbasin 16	7.1	0.1	0.0	0.0	1.5	0.0	7.3	16.0
Subbasin 17	9.9	1.3	14.3	0.0	0.9	0.0	45.9	72.3
Subbasin 18	0.0	0.1	0.0	2.6	0.0	0.0	23.3	26.0
Subbasin 19	0.1	0.1	1.3	19.0	0.0	0.0	9.0	29.5
Subbasin 20	44.5	1.8	0.1	0.0	14.3	0.0	25.6	86.3
Subbasin 21	35.6	6.2	0.0	0.0	34.8	0.0	0.4	77.0
Total	140.2	15.0	29.7	74.5	76.3	0.0	290.4	626.1

TABLE D-16 – PARTICULATE PHOSPHORUS LOAD BY LAND USE

Land Use	Particulate Phosphorus Load (lbs/year)
Construction	140.2
Road	15.0
Rural Residential	29.7
Upland Shrub	74.5
Urban	76.3
Water	0.0
Wyoming Big Sage Brush	290.4
Grand Total	626.1

APPLIED TRACTION CONTROL AND STREET SWEEPING

The City of Gillette applies scoria, a type of volcanic rock, to roads for traction control during inclement weather. The City has not kept track of the amount of scoria used until recently (Pers. Com, City of Gillette, Levi Jensen). The City estimates that it has applied 73 tons of scoria in the 2010 to 2011 winter season and 99 tons of scoria in the 2011 to 2012 winter season.

The City of Gillette has a comprehensive street sweeping program and while the City does not keep track of actual amounts of material that is swept up, there exists some data with which to estimate the amount. Table D-17 shows the estimate of sediment removed by the City's street sweeping effort.

TABLE D-17 – ESTIMATE OF STREET SWEEPING

Data Provided by the City	
14,600	hours of street sweeping since 2008
10	hours per shift
3	bin loads of sediment per shift
3	yd^3 of volume in the street sweeper
Calculated values	
4	years since 2008
3,650	hours of street sweeping per year
9	yd^3 of sediment removed by the street sweeper per shift
365	shifts per year
3,285	yd^3 of sediment removed by the street sweeper per year
100	lbs / ft^3 density
2,700	lbs / yd^3 density
1.35	tons / yd^3 density
4,435	tons per year of sediment removed by street sweeping

From the data, the City was able to provide, it seems that the street sweeping program removes considerably more sediment than is applied through traction control. However, it is also possible that some of what is swept up in the street sweeping bins is other debris besides sediment, such as grass clippings, twigs and branches, and leaves. Based on the City's estimate of the use of traction control scoria, and the estimated amount of street sweeping that the City engages in, traction control scoria was not included in the watershed sediment loading calculation.

DISSOLVED PHOSPHORUS LOAD

SIMPLE METHOD

The Simple Method estimates stormwater pollutant loads as the product of mean pollutant concentrations and runoff depths over specified periods of time (usually annual or seasonal) (Schueler, 1987). The Simple Method estimates stormwater runoff pollutant loads for urban areas. The technique requires a modest amount of information, including the subwatershed drainage area and impervious cover, stormwater runoff pollutant concentrations, and annual precipitation. With the Simple Method, land uses can be broken into specific areas, such as residential, commercial, industrial, and roadway and calculate annual pollutant loads for each type of land, or utilize more generalized pollutant values for land uses such as new suburban areas, older urban areas, central business districts, and highways.

The Simple Method estimates pollutant loads for chemical constituents as a product of annual runoff volume and pollutant concentration, as:

$$\mathbf{L = 0.226 * R * C * A}$$

Where: L = Annual load (lbs)
R = Annual runoff (inches)
C = Pollutant concentration (mg/l)
A = Area (acres)
0.226 = Unit conversion factor

The Simple Method calculates annual runoff as a product of annual runoff volume, and a runoff coefficient (Rv). Runoff volume is calculated as:

$$\mathbf{R = P * P_j * Rv}$$

Where: R = Annual runoff (inches)
P = Annual rainfall (inches)
P_j = Fraction of annual rainfall events that produce runoff
Rv = Runoff coefficient

In the Simple Method, the runoff coefficient is calculated based on impervious cover in the subwatershed.

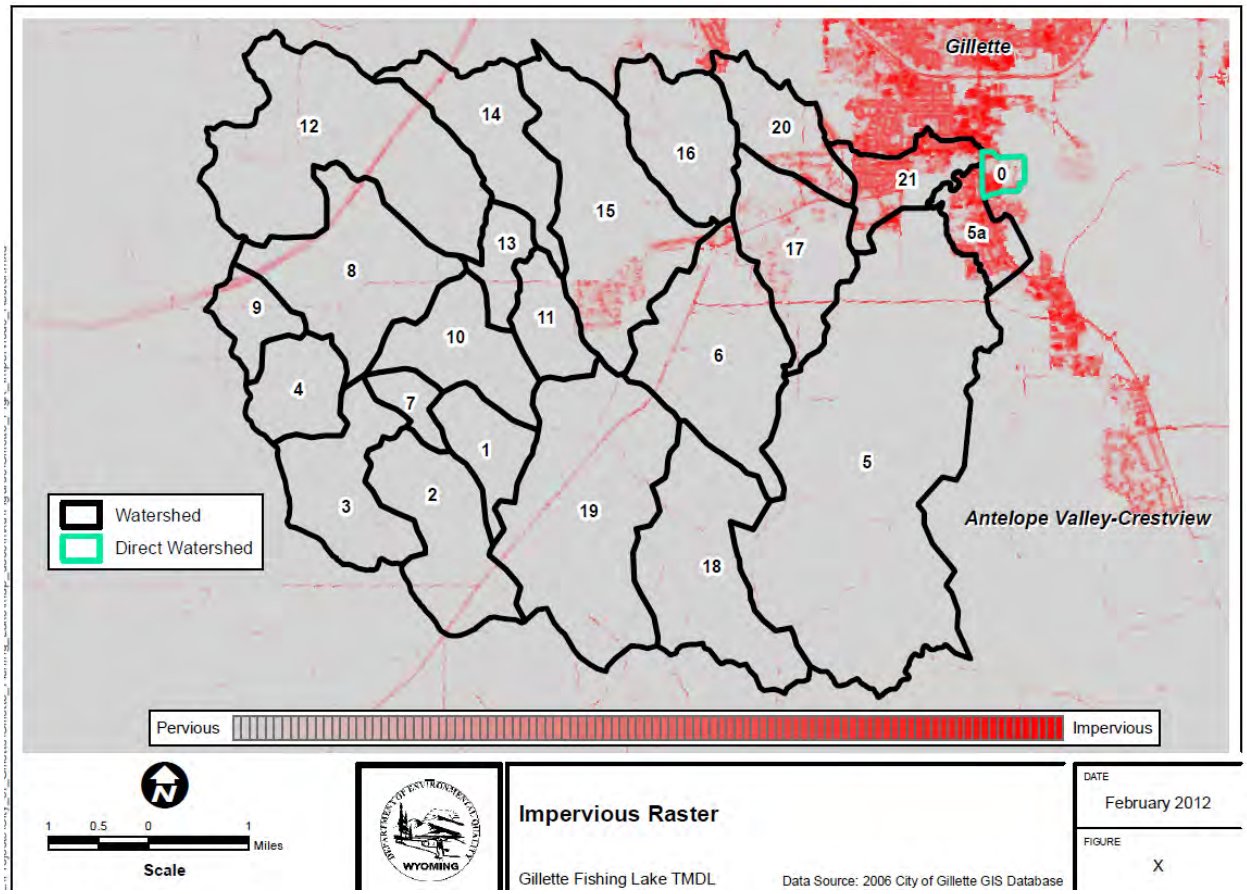
$$\mathbf{Rv=0.05+0.9Ia}$$

Where: Ia = Impervious fraction.

% IMPERVIOUS

The percent impervious area in the watershed was estimated using a % impervious GIS file created in 2006 by the City of Gillette. The data is shown in Figure D-8.

Figure D-8 – Impervious Raster



The vectorized % impervious data was compared to the land uses in the watershed. In the outer watershed areas, the impervious coverage did not match the land use coverage. The comparison of the two did note though that areas within City limits and areas closer to the City, specifically in subbasins Direct Watershed, 21, 5a, and 17, the imperviousness data was more accurate. Therefore, the % imperviousness for those watersheds were used as a basis for imperviousness in the other watersheds. For example, the imperviousness for the roads land use for subbasins Direct Watershed, 21, and 5a were calculated to be 75.45%, 53.79%, and 49.97%. For the Simple Method calculations for these three subbasins, these values were used for the % impervious variable. For the remaining watershed, the roads land use percent imperviousness value was calculated by averaging the three subbasin % impervious values, was set to 59.74%. The same procedure was followed to calculate the % imperviousness for the urban land use. The percent imperviousness in Subbasin 17 was utilized for rural residential landuse areas in all other subbasins, because the impervious GIS data was most accurate in this subbasin. Table D-18 shows the % imperviousness for all subbasins and land uses.

TABLE D-18 – PERCENT IMPERVIOUS BY SUBBASIN AND BY LAND USE

	Percent Impervious						
Subbasin / Land Use	**Construction**	**Road**	**Rural Residential**	**Upland Shrub**	**Urban**	**Water**	**Wyoming Big Sage Brush**
Direct Watershed	0	75.45	12.66	0	46.39	0	0
Subbasin 1	0	59.74	12.66	0	44.05	0	0
Subbasin 2	0	59.74	12.66	0	44.05	0	0
Subbasin 3	0	59.74	12.66	0	44.05	0	0
Subbasin 4	0	59.74	12.66	0	44.05	0	0
Subbasin 5	0	59.74	12.66	0	44.05	0	0
Subbasin 5a	0	49.97	12.66	0	42.31	0	0
Subbasin 6	0	59.74	12.66	0	44.05	0	0
Subbasin 7	0	59.74	12.66	0	44.05	0	0
Subbasin 8	0	59.74	12.66	0	44.05	0	0
Subbasin 9	0	59.74	12.66	0	44.05	0	0
Subbasin 10	0	59.74	12.66	0	44.05	0	0
Subbasin 11	0	59.74	12.66	0	44.05	0	0
Subbasin 12	0	59.74	12.66	0	44.05	0	0
Subbasin 13	0	59.74	12.66	0	44.05	0	0
Subbasin 14	0	59.74	12.66	0	44.05	0	0
Subbasin 15	0	59.74	12.66	0	44.05	0	0
Subbasin 16	0	59.74	12.66	0	44.05	0	0
Subbasin 17	0	59.74	12.66	0	44.05	0	0
Subbasin 18	0	59.74	12.66	0	44.05	0	0
Subbasin 19	0	59.74	12.66	0	44.05	0	0
Subbasin 20	0	59.74	12.66	0	44.05	0	0
Subbasin 21	0	53.79	12.66	0	43.46	0	0

Once the percent imperviousness was calculated for each land use in each subbasin, the runoff coefficient was calculated using the Equation **Rv=0.05+0.9Ia.** Table D-18 shows the results of applying this equation to all land uses in all subbasins.

TABLE D-19 – RUNOFF COEFFICIENTS BY SUBBASIN AND BY LAND USE

	Runoff Coefficients						
Subbasin / Land Use	**Construction**	**Road**	**Rural Residential**	**Upland Shrub**	**Urban**	**Water**	**Wyoming Big Sage Brush**
Direct Watershed	0.05	0.73	0.16	0.05	0.47	0.05	0.05
Subbasin 1	0.05	0.59	0.16	0.05	0.45	0.05	0.05
Subbasin 2	0.05	0.59	0.16	0.05	0.45	0.05	0.05
Subbasin 3	0.05	0.59	0.16	0.05	0.45	0.05	0.05
Subbasin 4	0.05	0.59	0.16	0.05	0.45	0.05	0.05
Subbasin 5	0.05	0.59	0.16	0.05	0.45	0.05	0.05
Subbasin 5a	0.05	0.50	0.16	0.05	0.43	0.05	0.05
Subbasin 6	0.05	0.59	0.16	0.05	0.45	0.05	0.05
Subbasin 7	0.05	0.59	0.16	0.05	0.45	0.05	0.05
Subbasin 8	0.05	0.59	0.16	0.05	0.45	0.05	0.05
Subbasin 9	0.05	0.59	0.16	0.05	0.45	0.05	0.05
Subbasin 10	0.05	0.59	0.16	0.05	0.45	0.05	0.05
Subbasin 11	0.05	0.59	0.16	0.05	0.45	0.05	0.05
Subbasin 12	0.05	0.59	0.16	0.05	0.45	0.05	0.05
Subbasin 13	0.05	0.59	0.16	0.05	0.45	0.05	0.05
Subbasin 14	0.05	0.59	0.16	0.05	0.45	0.05	0.05
Subbasin 15	0.05	0.59	0.16	0.05	0.45	0.05	0.05
Subbasin 16	0.05	0.59	0.16	0.05	0.45	0.05	0.05
Subbasin 17	0.05	0.59	0.16	0.05	0.45	0.05	0.05
Subbasin 18	0.05	0.59	0.16	0.05	0.45	0.05	0.05
Subbasin 19	0.05	0.59	0.16	0.05	0.45	0.05	0.05
Subbasin 20	0.05	0.59	0.16	0.05	0.45	0.05	0.05
Subbasin 21	0.05	0.53	0.16	0.05	0.44	0.05	0.05

RUNOFF VOLUME

The runoff volume is calculated by multiplying the annual rainfall, the runoff coefficient, and the fraction of annual rainfall events that produce runoff. The runoff coefficients are shown in Table D-20. The average annual rainfall in Gillette, Wyoming, obtained from the Western Regional Climate Center, from 1902 through 2011 is 15.75 inches.

Using an annual precipitation depth of 15.75, and a watershed area of 25,717 acres, the total volume of precipitation in the watershed is about 33,750 acre-ft of water. With an estimated average annual inflow of 666 acre-ft of inflow into Gillette Fishing Lake, plus direct precipitation onto the lake itself, the amount of precipitation that actually ends up in the lake could be as low as 2% on average. However, in the subbasins closer to the lake, where the storm system is able to convey nearly all the rainfall into runoff, the fraction will be closer to 0.9, which is what is usually recommended in the literature (Minnesota Pollution Control Agency, January 2008; New York State Department of Environmental Conservation, August 2010; North Carolina Department of Environment and Natural Resources, July 2007). For subbasins Direct Watershed, 5a, 17, 20, and 21, the fraction of annual rainfall events that produce runoff was set to 1, the same value as the Sediment Delivery Ratio for those subbasins. For all other basins, the value was set to 2%.

Runoff dissolved phosphorus concentrations for the urban, rural residential, and road land uses were obtained from EPA estimates. The EPA, in the 1983 document Results of the Nationwide Urban Runoff Program, estimated dissolved phosphorus concentrations in urban runoff. Table 6-12 in the TMDL shows the results of the study. For the residential use, mixed use, and commercial use, the median dissolved phosphorus concentrations were found to be 143 µg/l, 56 µg/l, and 80 µg/l, respectively. For the land use associations in Gillette Fishing Lake, the road and rural residential land uses were set to have a dissolved phosphorus runoff concentration of 143 µg/l, while the urban land use was set to have a dissolved phosphorus runoff concentration of 56 µg/l.

The final dissolved phosphorus loading estimate was calculated for each subbasin for each land use using the Simple Method approach. Table D-20 below shows the dissolved phosphorus load for each subbasin.

The areas of the watershed that have been identified as upland shrub and Wyoming Big Sagebrush are not considered to contribute to the watershed dissolved phosphorus load. The TP loading from these undeveloped, pervious areas is all in the form of particulate phosphorus.

TABLE D-20 – DISSOLVED PHOSPHORUS LOAD BY SUBBASIN AND BY LAND USE

	Dissolved Phosphorus Load (lbs/year)							
Subbasin / Landuse	**Construction**	**Road**	**Rural Residential**	**Upland Shrub**	**Urban**	**Water**	**Wyoming Big Sage Brush**	**Total**
Direct Watershed	0.00	0.61	0.00	0.00	5.99	0.00	0.00	6.60
Subbasin 1	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.06
Subbasin 2	0.00	0.05	0.43	0.00	0.00	0.00	0.00	0.48
Subbasin 3	0.00	0.02	0.22	0.00	0.00	0.00	0.00	0.24
Subbasin 4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subbasin 5	0.00	0.33	0.00	0.00	0.55	0.00	0.00	0.88
Subbasin 5a	0.00	10.89	0.00	0.00	20.62	0.00	0.00	31.51
Subbasin 6	0.00	0.22	0.60	0.00	0.03	0.00	0.00	0.84
Subbasin 7	0.00	0.01	0.13	0.00	0.00	0.00	0.00	0.14
Subbasin 8	0.00	0.18	0.56	0.00	0.13	0.00	0.00	0.87
Subbasin 9	0.00	0.05	0.00	0.00	0.14	0.00	0.00	0.19
Subbasin 10	0.00	0.10	0.98	0.00	0.00	0.00	0.00	1.07
Subbasin 11	0.00	0.06	0.62	0.00	0.01	0.00	0.00	0.69
Subbasin 12	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.08
Subbasin 13	0.00	0.02	0.19	0.00	0.00	0.00	0.00	0.21
Subbasin 14	0.00	0.03	0.04	0.00	0.00	0.00	0.00	0.07
Subbasin 15	0.00	0.22	0.37	0.00	0.55	0.00	0.00	1.14
Subbasin 16	0.00	0.09	0.01	0.00	0.34	0.00	0.00	0.44
Subbasin 17	0.00	9.18	34.69	0.00	3.35	0.00	0.00	47.22
Subbasin 18	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.06
Subbasin 19	0.00	0.14	0.36	0.00	0.00	0.00	0.00	0.50
Subbasin 20	0.00	8.44	0.18	0.00	22.47	0.00	0.00	31.10
Subbasin 21	0.00	12.20	0.00	0.00	31.60	0.00	0.00	43.79
Total	0.00	43.03	39.38	0.00	85.77	0.00	0.00	168.18

TABLE D-21 – DISSOLVED PHOSPHORUS LOAD BY LAND USE

Land Use	Dissolved Phosphorus Load (lbs/year)
Construction	0.0
Road	43.0
Rural Residential	39.4
Upland Shrub	0.0
Urban	85.8
Water	0.0
Wyoming Big Sage Brush	0.0
Grand Total	168.2

SEPTIC SYSTEM LOAD

The number of septic systems in the watershed, was obtained from the EPA's STEPL On-line Data Access System for the Gillette Fishing Lake Watershed. According the EPA database there are 35 septic systems in the watershed (EPA, 2010). The database also provides information about the population per septic system and the percent failure rate of septic systems in the area. USEPA's Spreadsheet Tool for Estimating Pollutant Load (STEPL) was used to calculate the TP loading to the lake from those 35 septic tanks. The values in the STEPL model related to septic tank loading, and the associated loading calculation are shown in Table D-22 below. Using EPA STEPL, with default parameters, the TP load from those septic tanks is approximately 1 pound per year.

TABLE D-22 – SEPTIC SYSTEMS

Value	Variable
35	No. of Septic Systems[1]
2.55	Population per Septic System[1]
0.27	Septic Failure Rate (%)[1]
0.0945	Failing Septic Systems[3]
0.240975	Population on Failing Septic Systems[3]
70	Typical septic overcharge flow rate (gal/day/person)[2]
16.868	Failing Septic Flow (gal/day)[3]
8	Wastewater per capita (mg/l)[2]
23.5	Average concentrations reaching the stream (from septic overcharge) (mg/L)[2]
0.000	P Load (lb/hr)[3]
1.21	P Load (lb/yr)[3]

[1] EPA STEPL On-line Data Access System
[2] Default EPA STEPL value
[3] EPA STEPL calculation result

FINAL WATERSHED TP LOADING

The sum of the particulate and dissolved TP loading is shown in Table D-23 by subbasin and land use, and Table D-24 shows the particulate and dissolved TP loading is shown in Table D-25 by land use only.

TABLE D-23 – TOTAL PHOSPHORUS (LBS/YEAR)

Row Labels	Construction	Road	Rural Residential	Upland Shrub	Urban	Water	Wyoming Big Sage Brush	Total
Direct Watershed	0.07	0.63	0.00	0.00	6.48	0.00	0.00	7.17
Subbasin 1	0.00	0.12	0.00	5.71	0.00	0.00	0.00	5.84
Subbasin 2	0.00	0.08	2.20	6.95	0.00	0.00	0.00	9.23
Subbasin 3	0.00	0.04	0.64	7.52	0.00	0.00	0.00	8.20
Subbasin 4	0.00	0.00	0.00	2.50	0.00	0.00	0.00	2.50
Subbasin 5	3.32	0.74	0.00	1.82	2.00	0.00	114.57	122.44
Subbasin 5a	22.14	14.97	0.00	0.00	40.91	0.00	16.19	94.21
Subbasin 6	6.92	0.46	2.82	0.00	0.10	0.00	16.69	27.00
Subbasin 7	0.00	0.02	0.46	1.56	0.00	0.00	0.00	2.04
Subbasin 8	0.00	0.26	1.86	2.47	0.45	0.00	2.22	7.25
Subbasin 9	0.00	0.08	0.00	1.34	0.46	0.00	0.00	1.88
Subbasin 10	0.19	0.19	4.31	1.89	0.00	0.00	0.00	6.58
Subbasin 11	4.30	0.12	3.11	0.00	0.06	0.00	0.02	7.62
Subbasin 12	0.00	0.16	0.00	19.53	0.00	0.00	7.40	27.10
Subbasin 13	0.00	0.04	0.94	0.00	0.00	0.00	1.61	2.60
Subbasin 14	0.26	0.06	0.12	1.68	0.00	0.00	11.34	13.46
Subbasin 15	5.77	0.40	1.73	0.00	2.38	0.00	8.80	19.07
Subbasin 16	7.12	0.18	0.01	0.00	1.83	0.00	7.25	16.40
Subbasin 17	9.88	10.49	48.95	0.00	4.26	0.00	45.92	119.51
Subbasin 18	0.00	0.12	0.00	2.55	0.00	0.00	23.35	26.02
Subbasin 19	0.15	0.27	1.64	18.95	0.00	0.00	8.96	29.97
Subbasin 20	44.48	10.21	0.27	0.00	36.81	0.00	25.63	117.40
Subbasin 21	35.60	18.42	0.00	0.00	66.37	0.00	0.42	120.81
Total	140.20	58.06	69.08	74.48	162.10	0.00	290.37	794.30

TABLE D-24 – TOTAL PHOSPHORUS LOAD BY LAND USE

Land Use	Total Phosphorus Load (lbs/year)
Construction	140
Road	58
Rural Residential	69
Upland Shrub	74
Urban	162

Water	0
Wyoming Big Sage Brush	290
Total	794

The total TP loading to Gillette Fishing lake can be described by the following equation:

Total TP loading to GFL = (watershed particulate TP load + watershed dissolved P load) + septic tank load + internal load

TABLE D-25 – PHOSPHORUS SOURCES

Load	TP (Tons per year)	Source
Particulate Phosphorus	626	RUSLE
Dissolved	168	Simple Method
Septic Tanks	1	STEPL
Internal Load	125	Difference between Lake Equations and watershed loading
Total TP Load to Gillette Fishing Lake	920	Lake Equations

INTERNAL TP LOADING

In lake sediments can release phosphorus to the water column. This can occur when the bottom of the water column, nearest the sediment becomes hypoxic. When a lake stratifies, water from the hypolimnion (bottom) does not mix with the surface water and DO in the hypolimnetic water column is consumed via microbial respiration and oxidation of other organic materials. Eventually, the hypolimnion becomes anoxic. Bacteria will begin to perform anearobic chemical reactions that release phosphate into the water column. At turnover, when the water in the lake mixes in the spring and fall, this rich source of phosphorus becomes available for algal production. In some cases, the lake bottom does not need to be fully hypoxic to release the phosphorus from the sediment. The oxygen demand of the bacteria breaking down the organic matter is strong enough to drive the DO concentrations in the first few centimeters of the sediment that anoxic conditions can occur in microhabitats that enable the reactions to occur that will release phosphorus.

Additionally, phosphorus can be release from the sediment when it has been resuspended for some reason, and the phosphorus is able to desorb from the sediment. This sediment resuspension mechanism can be wind mixing or rough fish feeding activity (bioturbation).

Gillette Fishing Lake has received phosphorus loads that, over time, have accumulated in the bottom sediment. Internal phosphorus loading from lake sediments can be an important component of the phosphorus budget for lakes, especially shallow lakes. In their textbook, *A Guide to the Restoration of Shallow Lakes*, Moss et al say that for shallow lakes, internal loading can be

considerable. Moss et al claim that he summer concentration can be doubled by internal loading and that the annual mean concentration can be increased by half.

For this TMDL analysis, once all external sources of phosphorus loading were identified, it was assumed that the remaining load must be originating from internal sources (i.e., lake bottom sediments), either through sediment diagenesis or sediment resuspension. It was necessary to make this assumption because there was very limited water quality sampling data available. On the June 19, 2009, and July 22, 2009, events, the measured DO concentration was down to hypoxic levels. On the August 20, 2009 sampling event, the measured in lake DO concentrations were higher, around 6.5 mg/L, but the *Chlorophyll a* concentrations in all lake sites were elevated, with all sites being above 100 µg/L. With such high concentrations of *chlorophyll a* evident in the lake, it is likely there was an algal bloom occurring at that time. If there had been another sampling event in September, there would have likely been an algal die off, causing more hypoxia. In fact, during the sediment survey which occurred in late August, there was an observed fish kill. Informal DO sampling showed hypoxic conditions in the lake. Also, as stated in Section 9.2, there have been documented winter fish kills in the lake. During the time leading up to these events, and for some time afterward, the DO must have been hypoxic, which would increase the amount of internal phosphorus loading.

As a check, to ensure that the 125 pounds per year of internal phosphorus loading was a reasonable value, a check calculation was performed. In a series of articles published from 1984 through 1998 (Nurnberg, 1984, 1987, 1994, and 1998), Nurnberg published a method for estimating internal loading of TP phosphorus. The Nurnberg method uses the number of days and total area of lake bottom that would have to have the right conditions to produce that internal load, multiplied by an average phosphorus release rate. The Nurnberg method of estimating internal load is a simple and accepted method. Wetzel (2001), in his widely recognized textbook, *Limnology*, refers to this method as a possible method to estimate internal loading.

The release rate used for this internal loading analysis was 20 mg per square meter per day, published in Nurnberg (1994) as a average value. Based on the lake sampling data, an estimate of the number of days hypoxic conditions might have occurred and an estimate of the total area of the lake that might have been hypoxic was made to cross check the back calculated internal phosphorus loading. Table D-26 shows the estimates of hypoxic days, hypoxic area, and the resulting internal phosphorus loading. As is evident by the resulting calculation, the back calculation for internal phosphorus loading of 125 pounds per year is reasonable.

TABLE D-26 – INTERNAL PHOSPHORUS LOADING ESTIMATE

	June	July	August	September	Total
Days	15	15	15	15	60
% of total Lake area	33%	50%	50%	50%	
Area (acres)	8.25	12.5	12.5	12.5	45.75
Area (m^2)	33,387	50,586	50,586	50,586	185,144
Load (mg)	10,015,970	15,175,712	15,175,712	15,175,712	55,543,104
Load (grams)	10,016	15,176	15,176	15,176	55,543
Load (lbs)	22	33	33	33	122

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APPENDIX E

1. INTRODUCTION

Predictive lake phosphorus (P) models are generally based on the principle of conservation of mass (aka mass balance) whereby P entering the lake (primarily from inflowing streams) must equal the sum of P exiting the lake (via outflowing streams) and P remaining in the lake (primarily associated with bottom sediments). Over the past 40 years, many models have been developed using data collected from many lakes and/or reservoirs. Such models typically use the same parameters for statistical analysis such as lake mean depth, lake flushing rate, and areal P load. These models are applicable world-wide because the scientific principles used to develop them are physically-based.

This memo describes the eleven lake P equations chosen for the Gillette Fishing Lake TMDL, which come from the four major lake P models (Vollenweider, Rekhow, Walker, Canfield/Bachmann) described below. The models represent the foundation of lake P modeling, whose equations can be found in software programs as well (e.g. BATHTUB), and are part of countless lake P TMDL projects. Each model contains multiple sets of equations which are the result of how the lake data set was split up for analysis. For example, equations differ between natural and artificial (i.e. reservoirs) lakes, anoxic vs. oxic hypolimnia, and shallow vs. deep lakes.

For this TMDL, relevant equations were analyzed for all four models because it is common practice to utilize more than one lake P model for lake analysis. There is inherent error in all models, so comparison of results between models and equations provides a range of predicted in-lake P concentrations to account for such error.

Parameters values used in the lake equations are given in Table 3 of the Gillette Fishing Lake TMDL document. For Gillette Fishing Lake, the mean depth used was z = 5.3 ft (1.62 m), the surface area 25 acres, and the volume 92 acre-ft. The hydraulic residence time (T_w), calculated from the lake volume, inflow, evaporation, and the assumption that the volume does not change, was calculated to be 0.15 years[1]. The phosphorus concentration (P) used was 177 µg/L for the current average growing season lake concentration and 45 µg/L for the target phosphorus concentration.

2. VOLLENWEIDER MODEL

The Vollenweider model is based on a five year study involving the examination of phosphorus load and response characteristics for about 200 waterbodies in 22 countries in Western Europe, North America, Japan and Australia. Vollenweider, working on the Organization for Economic Cooperation and Development (OECD) Eutrophication Study, developed a model describing the relationship of phosphorus load and the relative general acceptability of the water for recreational use (Vollenweider, 1975). Vollenweider found that when the annual phosphorus load to a lake is plotted as a function of the quotient of the mean depth and hydraulic residence time, lakes which were eutrophic tended to cluster in one area and oligotrophic lakes in another. Vollenweider developed a statistical relationship between areal annual phosphorus loading (Lp) to a lake normalized by mean depth (z) and hydraulic residence time (Tw), to predict lake phosphorus

[1] Note in Section IV, Canfield/Bachmann, the lake flushing rate p is the inverse of the hydraulic retention time (T_w) used by the other authors [Vollenweider, Reckhow, Walker].

concentration (P). This basic equation structure formed the basis for many other lake analyses. In 2010, the USEPA used the Vollenwieder equation to define numeric nutrient criteria in Florida (USEPA, 2010).

The OECD study was finally completed in 1982 with the publication of the report "Eutrophication of waters: monitoring, assessment and control" (Vollenweider, 1982). The 1982 report contained coefficient factors that could be used for specific types of lakes. The two models that best fit Gillette Fishing Lake are the model that contained all lakes as a dataset, and the model that contained only shallow lakes and reservoirs as a dataset.

Equations

1982 Combined OECD Model $$P = 1.55\left[\frac{P_{in}}{1+\sqrt{T_w}}\right]^{0.82}$$

1982 Shallow Lake and Reservoir Model $$P = 1.02\left[\frac{P_{in}}{1+\sqrt{T_w}}\right]^{0.88}$$

Where,
P = predicted in-lake total phosphorus concentration (mg/m^3)
T_w = lake hydraulic detention time (years)
L = areal total phosphorus load (mg/m^2 of lake area per year)
z = lake mean depth (meters)
$P_{in} = LT_w/z$ = average inflow concentration (mg/m^3)

Range of Values

Vollenweider, 1982 Combined OECD Model
$0.016 < T_w < 700$ yr
$0.0047 < P_{in} < 1425$ mg/l
$3.0 < P < 750$ mg/m^3

Vollenweider, 1982 Shallow Lake and Reservoir Model
$3.0 < P < 750$ mg/m^3
$0.016 < T_w < 700$ yr
$0.0047 < P_{in} < 1425$ mg/L

The annual total phosphorus is obtained by multiplying the areal load (L in mg/m^2) by the lake area (in square meters) and converting the resulting value to pounds.

3. RECKHOW MODEL

The 1977 anoxic lake model was first presented by Reckhow in his 1977 PhD dissertation (Reckhow, 1977) but published publically in 1979 in an EPA document discussing quantitative techniques for lake quality assessment (EPA, 1979). The 1979 Natural Lake Model was published publically in the same 1979 EPA document, but called the quasi-general model and further refined in a 1980 EPA document discussing phosphorus loading and lake responses, where it is called the

natural lake model (EPA, 1980). Both models derive from 20 to 30 general northern temperate lakes with a wide range of appropriate physical characteristics.

EUTROMOD is a watershed-scale nutrient loading and lake response model. It was developed by Ken Reckhow of Duke University. EUTROMOD can predict average growing season TP concentrations based on inputs about annual watershed loading from various sources. The model was designed to provide guidance and information for lake and reservoir management by using empirically derived relationships between in-lake concentrations and watershed loading. The EUTROMOD model is a one-dimensional model which is limited to well-mixed waterbodies.

Equations

1977 Anoxic Lake Model

$$P = \frac{L}{0.17z + 1.13 * \frac{z}{T_w}}$$

1979 Natural Lake Model

$$P = \frac{1000L}{11.6 + 1.2q_s}$$

EUTROMOD

$$P = \frac{P_{in}}{1 + \left(10.767 * T_w^{0.395} * z^{0.009} * P_{in}^{0.821} * 10^{0.024}\right)}$$

Where,
P = predicted in-lake total phosphorus concentration (µg/L)
T_w = lake hydraulic detention time (years)
L = areal total phosphorus load (mg/m^2 of lake area per year)
z = lake mean depth (meters)
q_s = Areal water loading or surface overflow rate, or m/yr or z/T_w
P_{in} = LT_w/z = average inflow concentration (mg/m^3)

Range of Values

Reckhow, 1979 Natural Lake Model
4 < P < 135 mg/m^3
70 < L < 31,400 mg/m^2-yr
0.75 < q_s < 187 m/yr

Reckhow,1977 Anoxic Lake Model
17 < P < 610 mg/m^3
0.024 < P_{in} < 0.621 mg/l

EUTROMOD
3 < P < 424 mg/m^3
0.008 < T_w < 285 yr
10 < P_{in} < 1334 mg/L
3.9 < z < 70.2 m

4. WALKER MODELS

BATHTUB is a United States Army Corps of Engineers model, used to model conditions in lakes or lake segments that are assumed to be completely mixed (Walker, 1981, 1982, 1985, and 1987). BATHTUB provides a framework for analysis and interpretation of monitoring data from a given reservoir. The parameters in the BATHTUB model come from a dataset that contains several hundred lakes.

Two phosphorus models used in the BATHTUB model are used here, for Gillette Fishing Lake, the reservoir model and the second order model. These models are described in the BATHTUB documentation and USACE report.

Equations

For both models, the main equation for both Walker models is:

$$P = [-1 + (1 + 4\ K\ A1\ P_i\ T_w)^{0.5}] / (2\ K\ A1\ T_w)$$

Where, for the reservoir model, which is Option 1 in the BATHTUB model A1 =

$$0.17\ Q_s/(Qs + 13.3)$$
$$Q_s = Max(Z/T_w, 4)$$

Or, for the second order model, which is Option 3 in the BATHTUB model, A1 = 0.1

Where,
P = predicted in-lake total phosphorus concentration (mg/L)
T_w = lake hydraulic detention time (years)
z = depth (m)
K = calibration factor, set to 1.
Q_s = surface overflow rate (m/year)
P_i = average inflow concentration (mg/L)
Where P_i = Total annual phosphorus load (mg) / Annual Inflow (L)

Range of Values

Walker, 1985 Reservoir Model
$1.5 < z < 58$ m
$0.13 < T_w < 1.91$ yr
$0.014 < P_{in} < 1.047$ mg/l

Walker, 1977 General Lake Model
$P < 900$ mg/m^3
$P_{in} < 1.0$ mg/L

5. CANFIELD-BACHMANN

The Canfield-Bachmann lake models are based on the Vollenweider (1969 as referenced in (Canfield, Bachmann 1981) general model of lake phosphorus loading. Canfield-Bachmann present empirically based phosphorus sediment coefficient equations that are used in the Vollenweider phosphorus loading models developed to be used as a lake management and research tool (Canfield, Bachmann 1981).

For Gillette Fishing Lake, both models were used. Canfield and Bachmann discuss that the presented methodology works equally well in natural or artificial lakes and the physical characteristics of the lake matches both lakes.

Equations

Natural Lakes

$$P = \frac{L}{z\left(0.162\left(L/z\right)^{0.458} + p\right)}$$

Artificial Lakes

$$P = \frac{L}{z\left(0.114\left(L/z\right)^{0.589} + p\right)}$$

Where:
P = predicted in-lake total phosphorus concentration (µg/L)
L = areal total phosphorus load (mg/m^2 of lake area per year)
z = lake mean depth (meters)
p = lake flushing rate (yr^{-1})

The annual total phosphorus is obtained by multiplying the areal load (L in mg/m^2) by the lake area (in square meters) and converting the resulting value to pounds. Note that p = 1/T_w.

Range of Values

Natural Lake Model
4 < P < 2600 mg/m^3
30 < L < 7600 mg/m^2-yr
0.2 < z < 307 m
0.001 < p < 183/yr

Artificial Lake Model
6 < P < 1500 mg/m^3
40 < L < 820,000 mg/m^2/yr
0.6 < z < 59 m
0.019 < p < 1800 /yr

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APPENDIX F

EPA REGION 8 TMDL REVIEW

TMDL Document Info:

Document Name:	**Draft Gillette Fishing Lake TMDL for Sediment and Total Phosphorus, Campbell County, Wyoming**
Submitted by:	**Wyoming Department of Environmental Quality**
Date Received:	**April 16, 2012**
Review Date:	**May 10, 2012**
Reviewer:	**Vern Berry, EPA**
Rough Draft / Public Notice / Final Draft?	**Public Notice Draft**
Notes:	

Reviewers Final Recommendation(s) to EPA Administrator (used for final draft review only):

- ☐ Approve
- ☐ Partial Approval
- ☐ Disapprove
- ☐ Insufficient Information

Approval Notes to Administrator:

This document provides a standard format for EPA Region 8 to provide comments to state TMDL programs on TMDL documents submitted to EPA for either formal or informal review. All TMDL documents are evaluated against the minimum submission requirements and TMDL elements identified in the following 8 sections:

1. Problem Description
   1.1. . TMDL Document Submittal Letter
   1.2. Identification of the Waterbody, Impairments, and Study Boundaries
   1.3. Water Quality Standards
2. Water Quality Target
3. Pollutant Source Analysis
4. TMDL Technical Analysis
   4.1. Data Set Description
   4.2. Waste Load Allocations (WLA)
   4.3. Load Allocations (LA)
   4.4. Margin of Safety (MOS)
   4.5. Seasonality and variations in assimilative capacity
5. Public Participation
6. Monitoring Strategy
7. Restoration Strategy
8. Daily Loading Expression

Under Section 303(d) of the Clean Water Act, waterbodies that are not attaining one or more water quality standard (WQS) are considered "impaired." When the cause of the impairment is determined to be a pollutant, a TMDL analysis is required to assess the appropriate maximum allowable pollutant loading rate. A TMDL document consists of a technical analysis conducted to: (1) assess the maximum pollutant loading rate that a waterbody is able to assimilate while maintaining water quality standards; and (2) allocate that assimilative capacity among the known sources of that pollutant**.** A well written TMDL document will describe a path forward that may be used by those who implement the TMDL recommendations to attain and maintain WQS.

Each of the following eight sections describes the factors that EPA Region 8 staff considers when reviewing TMDL documents. Also included in each section is a list of EPA's minimum submission requirements relative to that

section, a brief summary of the EPA reviewer's findings, and the reviewer's comments and/or suggestions. Use of the verb "must" in the minimum submission requirements denotes information that is required to be submitted because it relates to elements of the TMDL required by the CWA and by regulation. Use of the term "should" below denotes information that is generally necessary for EPA to determine if a submitted TMDL is approvable.

This review template is intended to ensure compliance with the Clean Water Act and that the reviewed documents are technically sound and the conclusions are technically defensible.

1. Problem Description

A TMDL document needs to provide a clear explanation of the problem it is intended to address. Included in that description should be a definitive portrayal of the physical boundaries to which the TMDL applies, as well as a clear description of the impairments that the TMDL intends to address and the associated pollutant(s) causing those impairments. While the existence of one or more impairment and stressor may be known, it is important that a comprehensive evaluation of the water quality be conducted prior to development of the TMDL to ensure that all water quality problems and associated stressors are identified. Typically, this step is conducted prior to the 303(d) listing of a waterbody through the monitoring and assessment program. The designated uses and water quality criteria for the waterbody should be examined against available data to provide an evaluation of the water quality relative to all applicable water quality standards. If, as part of this exercise, additional WQS problems are discovered and additional stressor pollutants are identified, consideration should be given to concurrently evaluating TMDLs for those additional pollutants. If it is determined that insufficient data is available to make such an evaluation, this should be noted in the TMDL document.

1.1 TMDL Document Submittal Letter

When a TMDL document is submitted to EPA requesting formal comments or a final review and approval, the submittal package should include a letter identifying the document being submitted and the purpose of the submission.

Minimum Submission Requirements.

☒ A TMDL submittal letter should be included with each TMDL document submitted to EPA requesting a formal review.

☒ The submittal letter should specify whether the TMDL document is being submitted for initial review and comments, public review and comments, or final review and approval.

☐ Each TMDL document submitted to EPA for final review and approval should be accompanied by a submittal letter that explicitly states that the submittal is a final TMDL submitted under Section 303(d) of the Clean Water Act for EPA review and approval. This clearly establishes the State's/Tribe's intent to submit, and EPA's duty to review, the TMDL under the statute**.** The submittal letter should contain such identifying information as the name and location of the waterbody and the pollutant(s) of concern, which matches similar identifying information in the TMDL document for which a review is being requested.

Recommendation:
☒ Approve ☐ Partial Approval ☐ Disapprove ☐ Insufficient Information ☐ N/A

Summary: *The availability of the public notice draft Gillette Fishing Lake TMDL document was submitted to EPA via the Wyoming Department of Environmental Quality (WDEQ) Listserve notification system on April 16, 2012. The notice included details of the public notice such as how to obtain a copy of the draft TMDL and where and when to submit comments. WDEQ requested comments by May 8, 2012.*

Comments: *No comments.*

1.2 Identification of the Waterbody, Impairments, and Study Boundaries

The TMDL document should provide an unambiguous description of the waterbody to which the TMDL is intended to apply and the impairments the TMDL is intended to address. The document should also clearly delineate the physical boundaries of the waterbody and the geographical extent of the watershed area studied. Any additional information needed to tie the TMDL document back to a current 303(d) listing should also be included.

Minimum Submission Requirements:

☒ The TMDL document should clearly identify the pollutant and waterbody segment(s) for which the TMDL is being established. If the TMDL document is submitted to fulfill a TMDL development requirement for a waterbody on the state's current EPA approved 303(d) list, the TMDL document submittal should clearly identify the waterbody and associated impairment(s) as they appear on the State's/Tribe's current EPA approved 303(d) list, including a full waterbody description, assessment unit/waterbody ID, and the priority ranking of the waterbody. This information is necessary to ensure that the administrative record and the national TMDL tracking database properly link the TMDL document to the 303(d) listed waterbody and impairment(s).

☒ One or more maps should be included in the TMDL document showing the general location of the waterbody and, to the maximum extent practical, any other features necessary and/or relevant to the understanding of the TMDL analysis, including but not limited to: watershed boundaries, locations of major pollutant sources, major tributaries included in the analysis, location of sampling points, location of discharge gauges, land use patterns, and the location of nearby waterbodies used to provide surrogate information or reference conditions. Clear and concise descriptions of all key features and their relationship to the waterbody and water quality data should be provided for all key and/or relevant features not represented on the map

☒ If information is available, the waterbody segment to which the TMDL applies should be identified/geo-referenced using the National Hydrography Dataset (NHD). If the boundaries of the TMDL do not correspond to the Waterbody ID(s) (WBID), Entity_ID information or reach code (RCH_Code) information should be provided. If NHD data is not available for the waterbody, an alternative geographical referencing system that unambiguously identifies the physical boundaries to which the TMDL applies may be substituted.

Recommendation:
☐ Approve ☒ Partial Approval ☐ Disapprove ☐ Insufficient Information

Summary:
Physical Setting and Listing History:
Gillette Fishing Lake is a manmade reservoir, located in the southeastern portion of the City of Gillette, in Campbell County, Wyoming. In 1949, Fishing Lake Dam was constructed on Donkey Creek, creating Gillette Fishing Lake. Gillette Fishing Lake currently has a mean depth of approximately 5.3 feet with a maximum depth of 10.4 feet and a storage volume of approximately 92 acre-feet. Total surface area of the lake is approximately 25 acres. The HUC Code for Gillette Fishing Lake is 10120201. This waterbody is located within the Upper Belle Fourche watershed which is part of the larger Missouri River basin. The waterbody identifier for Gillette Fishing Lake is WYBF101202010601_01. In 1996, Gillette Fishing Lake was included on Wyoming's §303(d) list of impaired waters as threatened for support of cold water fisheries and aquatic life other than fish due to siltation and phosphate.

Land use within the watershed is a mixture of sagebrush and upland shrub rangeland, urban, rural residential, construction and roads. The soils in the area are predominately moderately deep to very deep fine sandy loams, loams, and clay loams.

Impairment status:
The 2010 Wyoming Integrated Report for Surface Water Quality Assessment identified Gillette Fishing Lake (WYBF101202010601_01) as not supporting the following designated beneficial uses:

Waterbody	*Class / Size*	*Designated Use Not Supported*	*Cause*	*Source*
Gillette Fishing Lake WYBF101202010601_01	*2AB / 15.4 acres*	*Aquatic Life, Cold Water Fish*	*Phosphate*	*Non-Point Source*
Gillette Fishing Lake WYBF101202010601_01	*2AB / 15.4 acres*	*Aquatic Life, Cold Water Fish*	*Sediment*	*Non-Point Source*

In 2011, WDEQ/WQD changed the classification of Gillette Fishing Lake from a 2AB cold water fishery to a 2AB warm water fishery due to findings from a Use Attainability Assessment (UAA) completed by the City of Gillette. Although the classification has changed, the lake is still impaired for both sediment and phosphate.

Comments:

1. *Section 2.0, Watershed and Waterbody Description and Table 3 shows that the surface area of the lake is 25 acres. However, the 2010 303(d) list shows the size of the lake as 15.4 acres. These two sources should be reconciled, or an explanation should be added to the TMDL explaining the difference between the sizes.*

WDEQ Response: In section 2.0, a citation discussion was added to clarify where the 25 acres area was derived from.

1.3 Water Quality Standards

TMDL documents should provide a complete description of the water quality standards for the waterbodies addressed, including a listing of the designated uses and an indication of whether the uses are being met, not being met, or not assessed. If a designated use was not assessed as part of the TMDL analysis (or not otherwise recently assessed), the documents should provide a reason for the lack of assessment (e.g., sufficient data was not available at this time to assess whether or not this designated use was being met).

Water quality criteria (WQC) are established as a component of water quality standard at levels considered necessary to protect the designated uses assigned to that waterbody. WQC identify quantifiable targets and/or qualitative water quality goals that, if attained and maintained, are intended to ensure that the designated uses for the waterbody are protected. TMDLs result in maintaining and attaining water quality standards by determining the appropriate maximum pollutant loading rate to meet water quality criteria, either directly, or through a surrogate measurable target. The TMDL document should include a description of all applicable water quality criteria for the impaired designated uses and address whether or not the criteria are being attained, not attained, or not evaluated as part of the analysis. If the criteria were not evaluated as part of the analysis, a reason should be cited (e.g. insufficient data were available to determine if this water quality criterion is being attained).

Minimum Submission Requirements:

☒ The TMDL must include a description of the applicable State/Tribal water quality standard, including the designated use(s) of the waterbody, the applicable numeric or narrative water quality criterion, and the anti-degradation policy. (40 C.F.R. §130.7(c) (1)).

☒ The purpose of a TMDL analysis is to determine the assimilative capacity of the waterbody that corresponds to the existing water quality standards for that waterbody, and to allocate that assimilative capacity between the significant sources. Therefore, all TMDL documents must be written to meet the existing water quality standards for that waterbody (CWA §303(d) (1) (C)). *Note: In some circumstances, the load reductions determined to be necessary by the TMDL analysis may prove to be infeasible and may possibly indicate that the*

existing water quality standards and/or assessment methodologies may be erroneous. However, the TMDL must still be determined based on existing water quality standards. Adjustments to water quality standards and/or assessment methodologies may be evaluated separately, from the TMDL.

☐ The TMDL document should describe the relationship between the pollutant of concern and the water quality standard the pollutant load is intended to meet. This information is necessary for EPA to evaluate whether or not attainment of the prescribed pollutant loadings will result in attainment of the water quality standard in question.

☒ If a standard includes multiple criteria for the pollutant of concern, the document should demonstrate that the TMDL value would result in attainment of all related criteria for the pollutant. For example, both acute and chronic values (if present in the WQS) should be addressed in the document, including consideration of magnitude, frequency and duration requirements.

Recommendation:
☐ Approve ☒ Partial Approval ☐ Disapprove ☐ Insufficient Information

Summary: *A description of the applicable State water quality standards, including the designated use(s) of Gillette Fishing Lake and the narrative water quality criteria are located primarily in Section 4.0 of the TMDL document.*

Section 4.0, Impaired Designated Uses and Applicable Water Quality Standards, describes the uses that have been assigned to Gillette Fishing Lake. Gillette Fishing Lake is a classified as Class 2ABww waterbody as described by Chapter 1 of the Wyoming Water Quality Division Rules and Regulations:

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

In 1996, Gillette Fishing Lake was included on Wyoming's §303(d) list of impaired waters as threatened for support of cold water fisheries and aquatic life other than fish due to siltation and phosphate. In 2010, Wyoming's §303(d) list continued to include Gillette Fishing Lake as impaired due to siltation and phosphate.

The State of Wyoming does not have numeric water quality criteria for sediment or nutrients. For sediment, narrative standards that are applicable to Gillette Fishing Lake can be found in Chapter 1 of the Wyoming Water Quality Division Rules and Regulations, as follows:

- ***Settleable Solids –*** *"In all Wyoming surface waters, substances attributable to or influenced by the activities of man that will settle to form sludge, bank or bottom deposits shall not be present in quantities which could result in significant aesthetic degradation, significant degradation of habitat for aquatic life or adversely affect public water supplies, agricultural or industrial water use, plant life or wildlife".*

- ***Undesirable Aquatic Life*** *– "All Wyoming surface waters shall be free from substances and conditions or combinations thereof which are attributable to or influenced by the activities of man, in concentrations which produce undesirable aquatic life".*
- ***Biological Criteria*** *– "Class 1, 2 and 3 waters of the state must be free from substances, whether attributable to human-induced point source discharges or nonpoint source activities, in concentrations or combinations which will adversely alter the structure and function of indigenous or intentionally introduced aquatic communities".*

Comments:

1. *Section 4.0, page 12 of the TMDL document only includes narrative standards "for sediment" – could these same standards also be applicable to nutrients? If so, the document should include nutrients within the context of this section. If not, the applicable narrative standards for nutrients need to be added to the TMDL document.*

WDEQ Response: Section 4.0 has been updated to include all applicable Wyoming water quality standards.

2. *It seems that the narrative standards in WQD Rules Chapter 1, Section 16, Floating and Suspended Solids and perhaps Chapter 1, Section 17, Taste, Odor and Color, are also applicable to the sediment and nutrient impairments in Gillette Fishing Lake. We recommend that they be added to the TMDL document.*

WDEQ Response: See response to the above comment.

3. *The 2ABww classification for Gillette Fishing Lake includes protection of nongame fish, fish consumption, aquatic life other than fish, recreation, wildlife, industry, agriculture and scenic value uses. The TMDL document has a good explanation of how the aquatic life and fishing related recreational uses will be protected. However, the TMDL document needs to explain how the other designated uses were evaluated and include an analysis to demonstrate that those uses will be protected by the proposed sediment and total phosphorus targets, and/or include more stringent targets or secondary targets, as needed, to ensure protection of all designated uses for Gillette Fishing Lake.*

WDEQ Response: Discussion was added to section 4 to help explain how the other designated uses were evaluated. GFL was listed in 1996 and evaluation of other uses has not occurred. GFL will be assessed fully based on the monitoring sections schedule.

Background: On July 25, 2011, the United States District Court for the District of Columbia set aside the final total maximum daily load (TMDL), for the Anacostia River, finding that the TMDL was not adequate to ensure the water quality standards for all designated uses of the river. Anacostia Riverkeeper, Inc. v. Lisa Jackson, 2011 WL 3019922 (D. D.C. July 25, 2011). The court held that EPA's approval of a TMDL – that only expressly considered the effects of sediment and TSS pollution on plant and animal life and failed to consider the pollutant load level necessary to "safeguard all designated uses" – was arbitrary and capricious and in violation of the CWA and the Administrative Procedure Act (see summary: (http://www.courthousenews.com/2011/07/26/38477.htm).

4. *Section 9.0, Link Between TMDL Targets and Designated Uses, does a good job of demonstrating that the proposed targets, when met, will protect the fishery use and fishery related recreational use. However, as mentioned above, there is little mention of how those targets will protect the other designated uses of the lake: aquatic life other than fish, drinking water, recreation (e.g., boating, swimming), wildlife, industry, agriculture and scenic value. These uses need to be addressed in addition to the fishery use. The analysis demonstrating protection of these additional uses needs use definitive statements – the judge in the case cited above, found that statements such as "substantially improve" or "make the river certainly more desirable for other*

uses" were imprecise guesses and hopeful utterances that were lacking scientific basis. Part of this analysis could include a demonstration that the targets derived to protect the fishery are more stringent that the targets that would be needed to protect other designated uses (e.g., wildlife, industry, agriculture). More work may be necessary to show that the recreation and scenic value uses will be protected. We understand that WDEQ is planning on removing the drinking water use for the lake. We recommend adding a language to the TMDL that the lake is not used as a drinking water source and that WDEQ will work to remove the drinking water use in the near term.

WDEQ Response: Section 4.0 has been updated to include discussion about how the identified targets will protect other applicable uses. Language has been added about WDEQ removing the drinking water designated use.

5. *We understand that the sediment target was derived from the total phosphorus target. However, the narrative standards are aimed more at sediment than on nutrients. More emphasis on the linkage between the sediment target and the narrative standards needs to be made in the TMDL document. It may be helpful to review how it was determined that Gillette Fishing Lake is impaired by sediment. Was it related to the need to dredge sediment from the lake approximately every 10 years? If so, we recommend linking the sediment target to an acceptable accumulation rate (e.g., from literature for reservoirs) to show that once the TMDL reductions have been achieved, the deposition rate will be at normally expected range of values, and therefore will meet the narrative standards.*

WDEQ Response: Discussion was added to section 11.1 to reflect that a 78% reduction in sediment load should reduce the frequency for which dredging would be needed.

2.0 Water Quality Targets

TMDL analyses establish numeric targets that are used to determine whether water quality standards are being achieved. Quantified water quality targets or endpoints should be provided to evaluate each listed pollutant/water body combination addressed by the TMDL, and should represent achievement of applicable water quality standards and support of associated beneficial uses. For pollutants with numeric water quality standards, the numeric criteria are generally used as the water quality target. For pollutants with narrative standards, the narrative standard should be translated into a measurable value. At a minimum, one target is required for each pollutant/water body combination. It is generally desirable, however, to include several targets that represent achievement of the standard and support of beneficial uses (e.g., for a sediment impairment issue it may be appropriate to include a variety of targets representing water column sediment such as TSS, embeddeness, stream morphology, up-slope conditions and a measure of biota).

Minimum Submission Requirements:

☒ The TMDL should identify a numeric water quality target(s) for each waterbody pollutant combination. The TMDL target is a quantitative value used to measure whether or not the applicable water quality standard is attained. *Generally, the pollutant of concern and the numeric water quality target are, respectively, the chemical causing the impairment and the numeric criteria for that chemical (e.g., chromium) contained in the water quality standard. Occasionally, the pollutant of concern is different from the parameter that is the subject of the numeric water quality target (e.g., when the pollutant of concern is phosphorus and the numeric water quality target is expressed as a numerical dissolved oxygen criterion). In such cases, the TMDL should explain the linkage between the pollutant(s) of concern, and express the quantitative relationship between the TMDL target and pollutant of concern. In all cases, TMDL targets must represent the attainment of current water quality standards.*

☐ When a numeric TMDL target is established to ensure the attainment of a narrative water quality criterion, the numeric target, the methodology used to determine the numeric target, and the link between the pollutant of

concern and the narrative water quality criterion should all be described in the TMDL document. Any additional information supporting the numeric target and linkage should also be included in the document.

Recommendation:
☐ Approve ☒ Partial Approval ☐ Disapprove ☐ Insufficient Information

Summary: *Section 9.0, Link Between TMDL Targets and Designated Uses, identifies the water quality targets based on the aquatic life and recreational designated uses for Gillette Fishing Lake. Wyoming has not adopted numeric nutrient criteria, therefore, this TMDL includes an interim total phosphorus target specifically for Gillette Fishing Lake in order to complete the TMDL. The TMDL will be reevaluated once numeric nutrient criteria have been adopted for Wyoming and approved by EPA.*

The targets for Gillette Fishing Lake are:

- *In-Lake Total Phosphorus = 50 ug/L growing season average concentration*
- *In-Lake Sediment Accumulation rate = 252 tons per year.*

Comments: *The TP target has a good explanation of how it will protect the fishery uses for the lake. With some additional explanation the sediment target could be linked to the narrative criteria and the fishery uses as well. We recommend additional explanation be added to the document linking the TP target to the narrative standards. We also recommend evaluating the need to add secondary targets (e.g., Secchi disk target for recreational and/or scenic uses; algal bloom frequency for recreational and/or scenic uses) to support protection of the other designated uses.*
WDEQ Response: Additional discussion and analysis has been added in section 9.0 to explain how the TP target is linked to the fishery use and narrative standards. Secondary targets have been identified in section 11.0.

3. Pollutant Source Analysis

A TMDL analysis is conducted when a pollutant load is known or suspected to be exceeding the loading capacity of the waterbody. Logically then, a TMDL analysis should consider all sources of the pollutant of concern in some manner. The detail provided in the source assessment step drives the rigor of the pollutant load allocation. In other words, it is only possible to specifically allocate quantifiable loads or load reductions to each significant source (or source category) when the relative load contribution from each source has been estimated. Therefore, the pollutant load from each significant source (or source category) should be identified and quantified to the maximum practical extent. This may be accomplished using site-specific monitoring data, modeling, or application of other assessment techniques. If insufficient time or resources are available to accomplish this step, a phased/adaptive management approach may be appropriate. The approach should be clearly defined in the document.

Minimum Submission Requirements:

☒ The TMDL should include an identification of all potentially significant point and nonpoint sources of the pollutant of concern, including the geographical location of the source(s) and the quantity of the loading, e.g., lbs/per day. This information is necessary for EPA to evaluate the WLA, LA and MOS components of the TMDL.

☒ The level of detail provided in the source assessment should be commensurate with the nature of the watershed and the nature of the pollutant being studied. Where it is possible to separate natural background from nonpoint sources, the TMDL should include a description of both the natural background loads and the nonpoint source loads.

☒ Natural background loads should not be assumed to be the difference between the sum of known and quantified anthropogenic sources and the existing *in situ* loads (e.g. measured in stream) unless it can be demonstrated that all significant anthropogenic sources of the pollutant of concern have been identified, characterized, and properly quantified.

☒ The sampling data relied upon to discover, characterize, and quantify the pollutant sources should be included in the document (e.g. a data appendix) along with a description of how the data were analyzed to characterize and quantify the pollutant sources. A discussion of the known deficiencies and/or gaps in the data set and their potential implications should also be included.

Recommendation:
☐ Approve ☒ Partial Approval ☐ Disapprove ☐ Insufficient Information

Summary: *Section 2.0, Watershed and Waterbody Description, provides the landuse characterization for the drainage area of Gillette Fishing Lake. Rangeland and residential areas are the dominant landuses in the watershed. Table 2 and Figure 2 of the TMDL document include detailed landuse information for each subbasin within the watershed.*

Within the Gillette Fishing Lake watershed, all regulated point source discharges are reported to be from coal bed methane (CBM) extraction wells. The discharges from these outfalls are managed under Wyoming's Pollutant Discharge Elimination System program through permits issued by WDEQ/WQD. Sections 10.2.1 and 10.3.1, Point Sources, and Appendix B, includes more details on the number and location of the CBM outfalls and the wasteload allocations for sediment and phosphorus.

Section 5.0, Pollutant Sources, and the supporting RUSLE analysis in Appendix D of the TMDL document, indicates that the main sources of nonpoint loading of sediment and particulate phosphorus to Gillette Fishing Lake are primarily from overland runoff from subbasins that drain directly to the lake as well as runoff within the immediate vicinity of the lake from adjacent roadways and parking lots. An explanation of the derivation of dissolved phosphorus loading, from the watershed and from septic systems, are included in Sections 10.3.3.1.2 and 10.3.3.1.3 respectively. Internal loading of phosphorus from lake bottom sediments was estimated as explained in Section 10.3.3.1.4.

Comments:

1. *In several sections of the TMDL document there is mention of the 1995 Water Quality Study (i.e., 205j report). Some of the analysis in the TMDL assumes that the conditions described in the 205j report (e.g., hydrologic disconnections, channel stability) have not changed in the past 17 – 18 years. Was field reconnaissance efforts conducted during the development of the TMDL to verify if those conditions still exist? Is the 205j report available to the public? If so, we would like a copy, and it should be part of the administrative records for this TMDL.*

WDEQ Response: Field reconnaissance did not occur. Current aerial photos were used. The 205j report is available to the public and was submitted to EPA with the public review draft.

2. *Section 3.0, page 10, mentions the lake dredging conducted in 1973 and 1984. Approximately 32,808 cubic yards of material was removed in 1973, but no volume of material removed was provided in context of the 1984 dredging. Are there records of the amount of material removed in 1984? It seems that part of the assumptions built into the calculations of the sediment accumulation in the lake during the past 25 years is dependent on the volume of sediment remaining in the lake after it was dredged in 1984. It would be helpful to include the volume removed in 1984 and an explanation of the assumptions built into the accumulation rate calculations (e.g., it was assumed that the existing volume of sediment in the lake all accumulated during the period from 1984 to 2009; i.e., that the 1984 dredging removed all the accumulated sediment from the lake; this is likely an overestimation of the sediment accumulation rate since*

dredging operations are seldom able to remove all sediment). Also, related this issue, Table 9 includes values for the original lake volume and existing lake volume. We assume the existing volume is based on the 2009 sediment survey. Is the original volume based on the 1949 designs for the lake?

WDEQ Response: The volume of material removed in 1984 could not be identified. The current lake water volume is based on the sediment survey conducted in 2009. The original lake water volume is based on the original design plans for the lake in 1949, the 205j report and the additional volume added as described on page 10, after the 1973 dredging.

3. *Section 9.2.3, page 31, mentions an appropriate trophic state for Gillette Fishing Lake of 60. Is that a TP TSI? Further, that paragraph mentions that a TSI of 60 translates to a TP concentration of 50 ug/L, and includes a reference to Table 4. The reference to Table 4 seems to be an error. Should it be Table 13 instead? Also, it would be helpful to include a table that has the calculated TSI values for TP, chl-a and Secchi depth for each of the sampling dates shown in Figure 8 as well as the expected Secchi depth and chl-a values that correspond to a TP concentration of 50 ug/L.*

WDEQ Response: The trophic state of 60 is for TSI and discussion has been added to clarify. The correct table is now referenced.

4. TMDL Technical Analysis

TMDL determinations should be supported by a robust data set and an appropriate level of technical analysis**.** This applies to **all** of the components of a TMDL document. It is vitally important that the technical basis for **all** conclusions be articulated in a manner that is easily understandable and readily apparent to the reader.

A TMDL analysis determines the maximum pollutant loading rate that may be allowed to a waterbody without violating water quality standards. The TMDL analysis should demonstrate an understanding of the relationship between the rate of pollutant loading into the waterbody and the resultant water quality impacts. This stressor → response relationship between the pollutant and impairment and between the selected targets, sources, TMDLs, and load allocations needs to be clearly articulated and supported by an appropriate level of technical analysis. Every effort should be made to be as detailed as possible, and to base all conclusions on the best available scientific principles.

The pollutant loading allocation is at the heart of the TMDL analysis. TMDLs apportion responsibility for taking actions by allocating the available assimilative capacity among the various point, nonpoint, and natural pollutant sources. Allocations may be expressed in a variety of ways, such as by individual discharger, by tributary watershed, by source or land use category, by land parcel, or other appropriate scale or division of responsibility.

The pollutant loading allocation that will result in achievement of the water quality target is expressed in the form of the standard TMDL equation:

$$TMDL = \sum LAs + \sum WLAs + MOS$$

Where:

TMDL =		Total Pollutant Loading Capacity of the waterbody
LAs	=	Pollutant Load Allocations
WLAs	=	Pollutant Wasteload Allocations
MOS	=	The portion of the Load Capacity allocated to the Margin of safety.

Minimum Submission Requirements:

☒ A TMDL must identify the loading capacity of a waterbody for the applicable pollutant, taking into consideration temporal variations in that capacity. EPA regulations define loading capacity as the greatest amount of a pollutant that a water can receive without violating water quality standards (40 C.F.R. §130.2(f)).

☒ The total loading capacity of the waterbody should be clearly demonstrated to equate back to the pollutant load allocations through a balanced TMDL equation. In instances where numerous LA, WLA and seasonal TMDL capacities make expression in the form of an equation cumbersome, a table may be substituted as long as it is clear that the total TMDL capacity equates to the sum of the allocations.

☒ The TMDL document should describe the methodology and technical analysis used to establish and quantify the cause-and-effect relationship between the numeric target and the identified pollutant sources. In many instances, this method will be a water quality model.

☒ It is necessary for EPA staff to be aware of any assumptions used in the technical analysis to understand and evaluate the methodology used to derive the TMDL value and associated loading allocations. Therefore, the TMDL document should contain a description of any important assumptions (including the basis for those assumptions) made in developing the TMDL, including but not limited to:

(1) the spatial extent of the watershed in which the impaired waterbody is located and the spatial extent of the TMDL technical analysis;
(2) the distribution of land use in the watershed (e.g., urban, forested, agriculture);
(3) a presentation of relevant information affecting the characterization of the pollutant of concern and its allocation to sources such as population characteristics, wildlife resources, industrial activities etc…;
(4) present and future growth trends, if taken into consideration in determining the TMDL and preparing the TMDL document (e.g., the TMDL could include the design capacity of an existing or planned wastewater treatment facility);
(5) an explanation and analytical basis for expressing the TMDL through surrogate measures, if applicable. Surrogate measures are parameters such as percent fines and turbidity for sediment impairments; chlorophyll *a* and phosphorus loadings for excess algae; length of riparian buffer; or number of acres of best management practices.

☒ The TMDL document should contain documentation supporting the TMDL analysis, including an inventory of the data set used, a description of the methodology used to analyze the data, a discussion of strengths and weaknesses in the analytical process, and the results from any water quality modeling used. This information is necessary for EPA to review the loading capacity determination, and the associated load, wasteload, and margin of safety allocations.

☒ TMDLs must take critical conditions (e.g., steam flow, loading, and water quality parameters, seasonality, etc…) into account as part of the analysis of loading capacity (40 C.F.R. §130.7(c) (1)). TMDLs should define applicable critical conditions and describe the approach used to determine both point and nonpoint source loadings under such critical conditions. In particular, the document should discuss the approach used to compute and allocate nonpoint source loadings, e.g., meteorological conditions and land use distribution.

☐ Where both nonpoint sources and NPDES permitted point sources are included in the TMDL loading allocation, and attainment of the TMDL target depends on reductions in the nonpoint source loads, the TMDL document must include a demonstration that nonpoint source loading reductions needed to implement the load allocations are actually practicable [40 CFR 130.2(i) and 122.44(d)].

Recommendation:
☐ Approve ☒ Partial Approval ☐ Disapprove ☐ Insufficient Information

Summary: *The technical analysis pieces necessary to set appropriate water quality targets, complete the source assessment, estimate current loading, model reduction response, derive loading capacities and allocate loads can be found in several sections of the TMDL document.*

Sections 10.0, Existing Loading and 11.0, Target Load Capacity contain the core technical analysis components that tie together the source loading, the lake response, loading capacity and TMDL allocations for Gillette Fishing Lake.

The Revised Universal Soil Loss Equation (RUSLE) was used to estimate current sediment and particulate total phosphorus loading. An equation for reservoir trap efficiency was used to estimate the annual sediment load reaching Gillette Fishing Lake. The Iowa Lake Phosphorus Worksheet was used to estimate the average annual total phosphorus load to the lake, and the Simple Method was used to estimate the average annual dissolved phosphorus load to the lake. EPA's STEP-L Data Access System and mass balance relationships were used to complete remaining the technical analysis steps for these TMDLs.

Comments

1. *Because the point sources were given a zero wasteload allocation for both sediment and phosphorus it's not necessary to include a reasonable assurance (RA) demonstration in this TMDL document. However, due to the increased emphasis on the RA issue in all TMDLs, we recommend adding a brief sentence or two that explains that RA was considered for these TMDLs and it was determined that a RA demonstration is not needed because the point sources have no WLAs. We recommend that all TMDLs include a discussion of RA which can include the*

feasibility of implementing the BMPs necessary to meet the TMDL targets, any planned or funded implementation plans, follow-up monitoring plans, estimated milestone dates and plans to revise or revisit the TMDL document.

WDEQ Response: Discussion about reasonable assurance has been added to section 12.0.

2. *Table 14, page 34, shows some of the values used to calculate the sediment loading to the lake. Using the value for measured sediment accumulated over 25 years (41,540 cubic yards) and the trap efficiency in the lake (89 percent), the amount of sediment reaching the lake is given as 45,160 cubic yards or 30,480 tons. These values appear to be incorrect. We believe the correct value reaching the lake should be 46,674 cubic yards or 31,505 tons (46,674 x 0.89 = 41,540).*

WDEQ Response: The values were incorrect and the correct numbers have been applied.

4.1 Data Set Description

TMDL documents should include a thorough description and summary of all available water quality data that are relevant to the water quality assessment and TMDL analysis. An inventory of the data used for the TMDL analysis should be provided to document, for the record, the data used in decision making. This also provides the reader with the opportunity to independently review the data. The TMDL analysis should make use of all readily available data for the waterbody under analysis unless the TMDL writer determines that the data are not relevant or appropriate. For relevant data that were known but rejected, an explanation of why the data were not utilized should be provided (e.g., samples exceeded holding times, data collected prior to a specific date were not considered timely, etc…).

Minimum Submission Requirements:

☒ TMDL documents should include a thorough description and summary of all available water quality data that are relevant to the water quality assessment and TMDL analysis such that the water quality impairments are clearly defined and linked to the impaired beneficial uses and appropriate water quality criteria.

☒ The TMDL document submitted should be accompanied by the data set utilized during the TMDL analysis. If possible, it is preferred that the data set be provided in an electronic format and referenced in the document. If electronic submission of the data is not possible, the data set may be included as an appendix to the document.

Recommendation:
☒ Approve ☐ Partial Approval ☐ Disapprove ☐ Insufficient Information

Summary: *TMDL data collection includes many types of data such as land use, soil types, flow, topographic and water quality to name a few. Data from many sources need to be assembled and utilized to develop a good quality TMDL document. Water quality data are the most important type of data in a TMDL because it is used to relate the existing and predicted loading to the applicable standards. Section 7.0, Data Sources, summarizes the water quality sample planning, collection and analysis efforts that were conducted to develop the Gillette Fishing Lake TMDLs.*

Several water quality parameters were collected at three sampling sites on Gillette Fishing Lake from October 2008 through September 2009. Samples were collected during five sampling events that focused on seasonality, including dry fall, wet spring, wet summer, and dry summer. Tributary sampling of Donkey Creek, during the same period as the in-lake sampling, was conducted at the inlet and the outlet of Gillette Fishing Lake. Tributary sampling focused on different points of the hydrograph; samples were collected during ascending, peak, and descending flows. The full water quality data sets are included in Tables 6 and 7 of the TMDL document.

Comments: *No comments.*

4.2 Waste Load Allocations (WLA):

Waste Load Allocations represent point source pollutant loads to the waterbody. Point source loads are typically better understood and more easily monitored and quantified than nonpoint source loads. Whenever practical, each point source should be given a separate waste load allocation. All NPDES permitted dischargers that discharge the pollutant under analysis directly to the waterbody should be identified and given separate waste load allocations. The finalized WLAs are required to be incorporated into future NPDES permit renewals.

Minimum Submission Requirements:

☒ EPA regulations require that a TMDL include WLAs for all significant and/or NPDES permitted point sources of the pollutant. TMDLs must identify the portion of the loading capacity allocated to individual existing and/or future point source(s) (40 C.F.R. §130.2(h), 40 C.F.R. §130.2(i)). In some cases, WLAs may cover more than one discharger, e.g., if the source is contained within a general permit. If no allocations are to be made to point sources, then the TMDL should include a value of zero for the WLA.

☒ All NPDES permitted dischargers given WLA as part of the TMDL should be identified in the TMDL, including the specific NPDES permit numbers, their geographical locations, and their associated waste load allocations.

Recommendation:
☒ Approve ☐ Partial Approval ☐ Disapprove ☐ Insufficient Information

Summary: *There are multiple permitted point source discharges from coal bed methane drilling operations located within the watershed. Of the 61 outfalls within the watershed, 20 outfalls are permitted as an impoundment-type. Impoundment-type permits virtually eliminate discharge from these outfalls because they are hydrologically disconnected. Therefore, WDEQ assumes that these outfalls are not contributing sediment or phosphorus downstream to Gillette Fishing Lake.*

The remaining 41 outfall are permitted as direct discharge. These sites discharge either into an ephemeral channel or into intermittent streams. For the sites discharging into the ephemeral channels, WDEQ notes that the discharge does not likely reach Gillette Fishing Lake due to the losing nature of streams typical of this area. The sites discharging into the intermittent stream are located upstream of numerous small ponds that act as impoundments and are recommended to be treated similar to the impoundment-type outfalls (see Appendix B). Therefore, the TMDL document provides zero tons per year of sediment and zero pounds per year of phosphorus of loading from point sources to Gillette Fishing Lake.

Comments: *No comments.*

4.3 Load Allocations (LA):

Load allocations include the nonpoint source, natural, and background loads. These types of loads are typically more difficult to quantify than point source loads, and may include a significant degree of uncertainty. Often it is necessary to group these loads into larger categories and estimate the loading rates based on limited monitoring data and/or modeling results. The background load represents a composite of all upstream pollutant loads into the waterbody. In addition to the upstream nonpoint and upstream natural load, the background load often includes upstream point source loads that are not given specific waste load allocations in this particular TMDL analysis. In instances where nonpoint source loading rates are particularly difficult to quantify, a performance-based allocation approach, in which a detailed monitoring plan and adaptive management strategy are employed for the application of BMPs, may be appropriate.

Minimum Submission Requirements:

☒ EPA regulations require that TMDL expressions include LAs which identify the portion of the loading capacity attributed to nonpoint sources and to natural background. Load allocations may range from reasonably accurate estimates to gross allotments (40 C.F.R. §130.2(g)). Load allocations may be included for both existing and future nonpoint source loads. Where possible, load allocations should be described separately for natural background and nonpoint sources.

☒ Load allocations assigned to natural background loads should not be assumed to be the difference between the sum of known and quantified anthropogenic sources and the existing *in situ* loads (e.g., measured in stream) unless it can be demonstrated that all significant anthropogenic sources of the pollutant of concern have been identified and given proper load or waste load allocations.

Recommendation:

☐ Approve ☒ Partial Approval ☐ Disapprove ☐ Insufficient Information

Summary: *The load allocations for the Gillette Fishing Lake TMDLs are discussed in Sections 13.2.2 for sediment and 13.1.2 for phosphorus. No wasteloads are provided for the point sources in the watershed, therefore all of the loading capacity is allocated to the various nonpoint sources draining to the lake. The following load allocations are made:*

- *Sediment = 185 tons per year; and*
- *Total Phosphorus = 90 pounds per year*

Comments:

1. *The load allocations for sediment and phosphorus in sections 13.2.2 and 13.1.2 respectively, are inconsistent with the values shown in Tables 29 (252 tons per year) and 30 (160 pounds per year) and appear to be in error. We suggest checking the values and correcting as necessary. Also, the numbering or order of the sections is off, in that Section 13.2, Sediment, p 45 comes before Section 13.1, Phosphorus, p 46.*

WDEQ Response: The correct numbers have been placed in the tables. Incorrect section numbers have been adjusted.

4.4 Margin of Safety (MOS):

Natural systems are inherently complex. Any mathematical relationship used to quantify the stressor → response relationship between pollutant loading rates and the resultant water quality impacts, no matter how rigorous, will include some level of uncertainty and error. To compensate for this uncertainty and ensure water quality standards will be attained, a margin of safety is required as a component of each TMDL. The MOS may take the form of an explicit load allocation (e.g., 10 lbs/day), or may be implicitly built into the TMDL analysis through the use of conservative assumptions and values for the various factors that determine the TMDL pollutant load → water quality effect relationship. Whether explicit or implicit, the MOS should be supported by an appropriate level of discussion that addresses the level of uncertainty in the various components of the TMDL technical analysis, the assumptions used in that analysis, and the relative effect of those assumptions on the final TMDL. The discussion should demonstrate that the MOS used is sufficient to ensure that the water quality standards would be attained if the TMDL pollutant loading rates are met. In cases where there is substantial uncertainty regarding the linkage between the proposed allocations and achievement of water quality standards, it may be necessary to employ a phased or adaptive management approach (e.g., establish a monitoring plan to determine if the proposed allocations are, in fact, leading to the desired water quality improvements).

Minimum Submission Requirements:

☒ TMDLs must include a margin of safety (MOS) to account for any lack of knowledge concerning the relationship between load and wasteload allocations and water quality (CWA §303(d) (1) (C), 40 C.F.R. §130.7(c) (1)). EPA's 1991 TMDL Guidance explains that the MOS may be implicit (i.e., incorporated into the TMDL through conservative assumptions in the analysis) or explicit (i.e., expressed in the TMDL as loadings set aside for the MOS).

☐ If the MOS is implicit, the conservative assumptions in the analysis that account for the MOS should be identified and described. The document should discuss why the assumptions are considered conservative and the effect of the assumption on the final TMDL value determined.

☒ If the MOS is explicit, the loading set aside for the MOS should be identified. The document should discuss how the explicit MOS chosen is related to the uncertainty and/or potential error in the linkage analysis between the WQS, the TMDL target, and the TMDL loading rate.

☐ If, rather than an explicit or implicit MOS, the TMDL relies upon a phased approach to deal with large and/or unquantifiable uncertainties in the linkage analysis, the document should include a description of the planned phases for the TMDL as well as a monitoring plan and adaptive management strategy.

Recommendation:

☒ Approve ☐ Partial Approval ☐ Disapprove ☐ Insufficient Information

Summary: *Section 13.1.3., Margin of Safety, states that an explicit MOS is included in the TMDL. The MOS for Gillette Fishing Lake is 10 percent of the chosen target, 50 µg/L of TP. Therefore, the target with the MOS applied for TP is 45µg/L.*

Comments*: No comments.*

4.5 Seasonality and variations in assimilative capacity:

The TMDL relationship is a factor of both the loading rate of the pollutant to the waterbody and the amount of pollutant the waterbody can assimilate and still attain water quality standards. Water quality standards often vary based on seasonal considerations. Therefore, it is appropriate that the TMDL analysis consider seasonal variations, such as critical flow periods (high flow, low flow), when establishing TMDLs, targets, and allocations.

Minimum Submission Requirements:

☒ The statute and regulations require that a TMDL be established with consideration of seasonal variations. The TMDL must describe the method chosen for including seasonal variability as a factor. (CWA §303(d) (1) (C), 40 C.F.R. §130.7(c) (1)).

Recommendation:
☒ Approve ☐ Partial Approval ☐ Disapprove ☐ Insufficient Information

Summary: *In most lakes impacted by excessive nutrient and sediment loading, critical conditions typically occur during the ice-free months (i.e., the growing season from April through November). During these months, sediment and flow conditions, sediment re-suspension, and phosphorus loading are most likely to create conditions that result in summer and winter fish kills. Therefore, the TMDL calculations only incorporate the annual averages during the ice-free conditions.*

The existing and target sediment and phosphorus loads for Gillette Fishing Lake are expressed primarily as annual averages. The models used to calculate the existing and target sediment and phosphorus loads use monthly flow, accumulated sediment, and phosphorus concentrations to calculate average annual sediment and phosphorus loading.

Comments: *No comments.*

5. Public Participation

EPA regulations require that the establishment of TMDLs be conducted in a process open to the public, and that the public be afforded an opportunity to participate. To meaningfully participate in the TMDL process it is necessary that stakeholders, including members of the general public, be able to understand the problem and the proposed solution. TMDL documents should include language that explains the issues to the general public in understandable terms, as well as provides additional detailed technical information for the scientific community. Notifications or solicitations for comments regarding the TMDL should be made available to the general public, widely circulated, and clearly identify the product as a TMDL and the fact that it will be submitted to EPA for review. When the final TMDL is submitted to EPA for approval, a copy of the comments received by the state and the state responses to those comments should be included with the document.

Minimum Submission Requirements:

☒ The TMDL must include a description of the public participation process used during the development of the TMDL (40 C.F.R. §130.7(c) (1) (ii)).

☐ TMDLs submitted to EPA for review and approval should include a summary of significant comments and the State's/Tribe's responses to those comments.

Recommendation:
☒ Approve ☐ Partial Approval ☐ Disapprove ☐ Insufficient Information

Summary: *The Public Participation section of the TMDL document describes the public participation process that has occurred during the development of the TMDL. In particular, public participation was encouraged through a public meeting and a stakeholders meeting in November 2008.*

Comments: *We recommend including a more complete summary of the public participation that has occurred from the time work began on developing the Gillette Fishing Lake TMDL document in 2008, up to and including the public comment period. Information about the public notice should be included such as how it was made available to the public (e.g., newspaper, mailing list, etc.).*

When the final TMDL is submitted to EPA for approval, a summary of the comments received by the state and the state responses to those comments should be included with the document.

WDEQ Response: The public comment section has been updated to reflect all public participation that occurred and includes a summary of the public comments.

6. Monitoring Strategy

TMDLs may have significant uncertainty associated with the selection of appropriate numeric targets and estimates of source loadings and assimilative capacity. In these cases, a phased TMDL approach may be necessary. For Phased TMDLs, it is EPA's expectation that a monitoring plan will be included as a component of the TMDL document to articulate the means by which the TMDL will be evaluated in the field, and to provide for future supplemental data that will address any uncertainties that may exist when the document is prepared.

Minimum Submission Requirements:

☐ When a TMDL involves both NPDES permitted point source(s) and nonpoint source(s) allocations, and attainment of the TMDL target depends on reductions in the nonpoint source loads, the TMDL document should include a monitoring plan that describes the additional data to be collected to determine if the load reductions provided for in the TMDL are occurring.

☐ Under certain circumstances, a phased TMDL approach may be utilized when limited existing data are relied upon to develop a TMDL, and the State believes that the use of additional data or data based on better analytical techniques would likely increase the accuracy of the TMDL load calculation and merit development of a second phase TMDL. EPA recommends that a phased TMDL document or its implementation plan include a monitoring plan and a scheduled timeframe for revision of the TMDL. These elements would not be an intrinsic part of the TMDL and would not be approved by EPA, but may be necessary to support a rationale for approving the TMDL. http://www.epa.gov/owow/tmdl/tmdl_clarification_letter.pdf

Recommendation:
☒ Approve ☐ Partial Approval ☐ Disapprove ☐ Insufficient Information

Summary: *Further monitoring is needed to create baseline conditions for Gillette Fishing Lake and to monitor the effectiveness of future implementation plans. Additional monitoring will also provide the necessary information to determine progress toward attainment of the TMDL and when designated uses are supported in Gillette Fishing Lake. Monitoring recommendations include, but are not limited to, the following:*

- *Conduct seasonal (spring, summer, and fall) monitoring of phosphorus at the three sampling locations in Gillette Fishing Lake.*
- *Take monthly (April through November) measurements of flow and phosphorus at the inlet and outlet to Gillette Fishing Lake.*

- *Conduct a sediment survey of the accumulated sediment at the bottom of Gillette Fishing Lake every 5 years.*
- *WGFD should continue to stock and monitor the fish populations within Gillette Fishing Lake.*

Comments: *No comments.*

7. Restoration Strategy

The overall purpose of the TMDL analysis is to determine what actions are necessary to ensure that the pollutant load in a waterbody does not result in water quality impairment. Adding additional detail regarding the proposed approach for the restoration of water quality is not currently a regulatory requirement, but is considered a value added component of a TMDL document. During the TMDL analytical process, information is often gained that may serve to point restoration efforts in the right direction and help ensure that resources are spent in the most efficient manner possible. For example, watershed models used to analyze the linkage between the pollutant loading rates and resultant water quality impacts might also be used to conduct "what if" scenarios to help direct BMP installations to locations that provide the greatest pollutant reductions. Once a TMDL has been written and approved, it is often the responsibility of other water quality programs to see that it is implemented. The level of quality and detail provided in the restoration strategy will greatly influence the future success in achieving the needed pollutant load reductions.

Minimum Submission Requirements:

☒ EPA is not required to and does not approve TMDL implementation plans. However, in cases where a WLA is dependent upon the achievement of a LA, "reasonable assurance" is required to demonstrate the necessary LA called for in the document is practicable). A discussion of the BMPs (or other load reduction measures) that are to be relied upon to achieve the LA(s), and programs and funding sources that will be relied upon to implement the load reductions called for in the document, may be included in the implementation/restoration section of the TMDL document to support a demonstration of "reasonable assurance".

Recommendation:
☒ Approve ☐ Partial Approval ☐ Disapprove ☐ Insufficient Information

Summary: *Section 16.0, Implementation Plan, mention goals and objectives that are suggested for the implementation phase of the project. WDEQ/WQD, CCCD, and the City are prepared to continue efforts to implement BMPs by updating the Gillette Fishing Lake Water Quality Improvement Plan. Through this plan, goals and objectives will be determined to address implementation of BMPs to improve the water quality of Gillette Fishing Lake.*

The goals and objectives address the following general watershed concerns: urban/surface runoff, stakeholder coordination, education, information dissemination, and water quality monitoring. Some of these items are from the Gillette Fishing Lake Water Quality Improvement Plan, and additional items will help to reduce the sediment and phosphorus loading. The Plan includes further detail on each of the following loading reduction efforts:

Landscape Management;
Control of Urban Runoff;
Dredge Gillette Fishing Lake;
Construct natural sedimentation pond(s) at the Donkey Creek inlet;
Agriculture Phosphorus Management;
Stakeholder Coordination;
Public Participation.

According to Wyoming's 2008 TMDL workplan, this TMDL will be reassessed at least every 5 years. Reassessments are an iterative approach to refining the TMDL as new information becomes available or environmental conditions in the watershed change significantly over time. This approach also allows WDEQ/WQD to use a feedback loop to determine if the initial sediment and TP load targets are effective in reaching the ultimate goal of having Gillette Fishing Lake meet water quality standards of fully supporting its designated uses. Revisions to the water quality standards may warrant the recalculation of the TMDLs. If WDEQ/WQD proposes changes to the Gillette Fishing Lake TMDL after future reassessment, a new public comment period and review by the U.S. Environmental Protection Agency will occur.

A Section 319 Project Implementation Plan for Gillette Fishing Lake has been written and funding has been approved. Implementation activities will begin in 2012.

Comments: *We recommend that part of the implementation planning include consideration of revisions to existing maintenance practices. For example, there is mention that the Stormceptors are cleaned once per year to remove collected sediment and debris, whereas more frequent cleaning may be necessary to capture and remove more of the sediment load.*
WDEQ Response: This comment was noted. WDEQ will work with the City of Gillette to ensure that the management measures applied will be adequate to reduce the pollutants.

8. Daily Loading Expression

The goal of a TMDL analysis is to determine what actions are necessary to attain and maintain WQS. The appropriate averaging period that corresponds to this goal will vary depending on the pollutant and the nature of the waterbody under analysis. When selecting an appropriate averaging period for a TMDL analysis, primary concern should be given to the nature of the pollutant in question and the achievement of the underlying WQS. However, recent federal appeals court decisions have pointed out that the title TMDL implies a "daily" loading rate. While the most appropriate averaging period to be used for developing a TMDL analysis may vary according to the pollutant, a daily loading rate can provide a more practical indication of whether or not the overall needed load reductions are being achieved. When limited monitoring resources are available, a daily loading target that takes into account the natural variability of the system can serve as a useful indicator for whether or not the overall load reductions are likely to be met. Therefore, a daily expression of the required pollutant loading rate is a required element in all TMDLs, in addition to any other load averaging periods that may have been used to conduct the TMDL analysis. The level of effort spent to develop the daily load indicator should be based on the overall utility it can provide as an indicator for the total load reductions needed.

Minimum Submission Requirements:

☐ The document should include an expression of the TMDL in terms of a daily load. However, the TMDL may also be expressed in temporal terms other than daily (e.g., an annual or monthly load). If the document expresses the TMDL in additional "non-daily" terms the document should explain why it is appropriate or advantageous to express the TMDL in the additional unit of measurement chosen.

Recommendation:
☐ Approve ☒ Partial Approval ☐ Disapprove ☐ Insufficient Information

Summary: *The Gillette Fishing Lake sediment and total phosphorus TMDLs only include annual loads expressed as tons per year and pounds per year respectively.*

Comments: *Based upon a District of Columbia Circuit Court of Appeals decision related to a TMDL written for the Anacostia River, all TMDLs must include loads expressed in daily terms. We recognize that pollutants such as sediment and phosphorus may be more appropriately calculated on a yearly basis and that the narrative water quality standards for these pollutants do not have numeric daily magnitude or frequency components. However, a daily expression of sediment and phosphorus loading needs to be part of this TMDL document.*

Wyoming may want to simply divide the annual loads by 365 to derive a daily loading estimate and include an explanation that these pollutants and this daily estimate methodology are difficult to measure in daily increments and that the resulting daily values should be viewed as average daily estimates that will likely be higher during wet periods and lower during dry periods. Alternative methods for deriving and expressing daily loads are explained in EPA's "Options for Expressing Daily Loads in TMDLs" - http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/upload/2007_06_26_tmdl_draft_daily_loads_tech-2.pdf.

WDEQ Response: All loads have been changed and are reported in a daily time step.