TOTAL MAXIMUM DAILY LOAD
WATER QUALITY STUDY
BROUGH, RED FLEET, AND
STEINAKER RESERVOIRS

Prepared For

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Utah Department of Environmental Quality
Division of Water Quality
TMDL Section

Brough Reservoir TMDL

EPA Approval Date: August 22, 2008

Waterbody ID	Lower Green - Diamond Watershed HUC # 14060001
Location	Uintah County, Northern Utah
Pollutants of Concern	Dissolved Oxygen
Impaired Beneficial Uses	Class 3A: Protected for cold water species and their food chain.
Current Load Loading Capacity (TMDL) Margin of Safety (MOS)	298 kg/year of total phosphorus 9 kg/year of total phosphorus (97% reduction) Implicit
Wasteload Allocation Load Allocation	No Point Sources, 0 lbs/year of total phosphorus 9 kg/year of total phosphorus
Defined Targets/Endpoints	1) Average Trophic State Index between 40 and 50. 2) No fish kills. 3) Decrease the Dominance of Blue-Green Algae. 4) Total phosphorus concentrations less than 0.025 mg/L (in-lake) and 0.05 mg/L (tributary inflow) 5) Dissolved oxygen concentrations of at least 4.0 mg/L in at least 50% of the water column.
Implementation Strategy	1) No significant sources identified 2) Phased implementation approach to pursue development of tiered aquatic life uses and use attainability analysis to better characterize beneficial use support.

Utah Department of Environmental Quality

Division of Water Quality

TMDL Section

Red Fleet Reservoir TMDL

EPA Approval Date: August 22, 2008

Waterbody ID	Ashley-Brush Watershed HUC # 14060002
Location	Uintah County, Northern Utah
Pollutants of Concern	Dissolved Oxygen
Impaired Beneficial Uses	Class 3A: Protected for cold water species and their food chain.
Current Load Loading Capacity (TMDL) Margin of Safety (MOS)	1,489 kg/year of total phosphorus 150 kg/year of total phosphorus Implicit
Wasteload Allocation Load Allocation	No Point Sources, 0 lbs/year of total phosphorus 150 kg/year of total phosphorus (90% reduction)
Defined Targets/Endpoints	1) Average Trophic State Index between 40 and 50. 2) No fish kills. 3) Decrease the Dominance of Blue-Green Algae. 4) Total phosphorus concentrations less than 0.025 mg/L (in-lake) and 0.05 mg/L (tributary inflow). 5) Dissolved oxygen concentrations of at least 4.0 mg/L in at least 50% of the water column.
Implementation Strategy	1) No significant sources identified 2) Phased implementation approach to pursue development of tiered aquatic life uses and use attainability analysis to better characterize beneficial use support.

Utah Department of Environmental Quality
Division of Water Quality
TMDL Section

Steinaker Reservoir TMDL

EPA Approval Date: August 22, 2008

Waterbody ID	Ashley-Brush Watershed HUC # 14060002
Location	Uintah County, Northern Utah
Pollutants of Concern	Dissolved Oxygen
Impaired Beneficial Uses	Class 3A: Protected for cold water species and their food chain.
Current Load Loading Capacity (TMDL) Margin of Safety (MOS)	777 kg/year of total phosphorus 22 kg/year of total phosphorus Implicit
Wasteload Allocation Load Allocation	No Point Sources, 0 lbs/year of total phosphorus 22 kg/year of total phosphorus (97% reduction)
Defined Targets/Endpoints	1) Average Trophic State Index between 40 and 50. 2) No fish kills. 3) Decrease the Dominance of Blue-Green Algae. 4) Total phosphorus concentrations less than 0.025 mg/L (in-lake) and 0.05 mg/L (tributary inflow). 5) Dissolved oxygen concentrations of at least 4.0 mg/L in at least 50% of the water column.
Implementation Strategy	1) No significant sources identified 2) Phased implementation approach to pursue development of tiered aquatic life uses and use attainability analysis to better characterize beneficial use support.

TMDL STUDY
BROUGH, RED FLEET, AND STEINAKER RESERVOIRS

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1.0 INTRODUCTION

Brough, Steinaker and Red Fleet Reservoirs were placed on Utah's 303(d) list of impaired waters due to failure to support these waterbody's designated 3A beneficial use for protection of cold water species of game fish and other cold water aquatic life, including the necessary aquatic organisms in their food chain. The impairment is due to low dissolved oxygen concentrations. The State is required to develop Total Maximum Daily Loads (TMDLs) for waters on the 303(d) list, defining the maximum amount of pollutant loading that the waters can receive and still meet water quality standards. This report contains the TMDL assessment for these three reservoirs.

This report identifies the applicable water quality standards and designated beneficial uses for each of the reservoirs (**Section 1**), describes the contributing watersheds for each of the reservoirs (**Section 2**), discusses reservoir characteristics and operations (**Section 3**), and evaluates the extent of the impairment and the TMDLs necessary to attain water quality standards and restore the beneficial uses for each reservoir (**Section 4**). Conclusions are provided in **Section 5**.

1.1 Water Quality Standards

Utah's Standards of Quality for Waters of the State (§R317-2, UAC) establishes numeric criteria for beneficial use 3A (protected for cold water species of game fish and other cold water aquatic life, including the necessary aquatic organisms in their food chain) using conventional parameters such as dissolved oxygen, temperature, and pH.

The procedure used by the Utah Division of Water Quality (DWQ) to evaluate Class 3 (aquatic life) beneficial uses for lakes and reservoirs is as follows (DWQ, 2006):

> "The dissolved oxygen criterion has been defined using the 1-day minimum dissolved oxygen concentration of 4.0 mg/L. State standards account for the fact that anoxic or low dissolved oxygen conditions may exist in the bottom of deep reservoirs and therefore, the dissolved oxygen standard is applied as follows. When the concentration is above 4.0 mg/L for greater than 50% of the water column depth, a fully supporting status is assigned. When 25-50% of the water column is above 4.0 mg/L, it is designated as partial supporting and when less than 25% of the water column exceeds the 4.0 mg/L criteria, it is designated as not supporting its defined beneficial use.

> Having determined support status for individual pollutants or stressors, an overall use support designation is determined based on a combination of the individual pollutant or stressor support designations. A 'not supporting' status is assigned to a body of water when at least two of the basic criteria (dissolved oxygen, pH or temperature) were found to be not supportive. A 'fully supporting' status is assigned when all of the criteria were found to be fully supporting. All other assessment units are assigned a 'partially supporting' status for criteria found in the various remaining combinations. The initial support status may be modified through an evaluation of the trophic state index (TSI), winter dissolved oxygen conditions with reported fish kills, and the presence of significant blue green algal populations in the phytoplankton community. This evaluation, although based to an extent on professional judgment, could shift initial support status ranking downward if two of the three criteria indicate there is was impairment in the water quality".

The total phosphorus indicator for cold-water game fish is 0.025 mg/L for lakes and reservoirs and is considered in the data review for the reservoirs when evaluating dissolved oxygen levels.

Additional criteria are used to determine the degree of beneficial use support for lakes and reservoirs. Utah's 2006-303(d) list (DWQ, 2006) provides guidance on how to apply the numeric water quality criteria for determining the degree of beneficial use support. These criteria are used to evaluate the listing and delisting of a waterbody. The 303(d) criteria for assessing the degree of support for beneficial use Class 3A is provided in Table 1

Table 1
Criteria for Assessing Aquatic Life Beneficial Use Support
Classes 3A, 3B, 3C, 3D

Degree of Use Support	Conventional Parameters [1] (pH, DO, Temperature)
Full	For any one pollutant, criterion was exceed only once or was not exceeded in < 10% of the samples if the criterion was exceeded at least two times.
Partial	For any one pollutant, criterion was exceeded two times, and criterion was exceeded in more than 10% but not more than 25% of the samples.
Non	For any one pollutant, criterion was exceeded two times, and criterion was exceeded in more than 25% of the samples.
1 - During the recent drought, areas of the state ranged from moderate to extreme drought conditions. For conventional parameters, especially temperature, a determination was made as to whether or not the violations of the state standards were caused by the drought conditions. Data were compared against historical data at monitoring sites to assist in making the decision; flow data and observations by field crews were also used in making the determination whether to list conventional parameters for an Assessment Unit or not.	

As part of the data evaluation, tributary water quality data were also reviewed. The numeric criteria for beneficial use 3A rivers was used to identify potentially impacted waters entering the reservoirs. The water quality criteria used to evaluate tributary waters is a dissolved oxygen standard of at least 6.5 mg/L and Total Phosphorus not to exceed 0.05 mg/L.

1.2 Beneficial Uses and 303(d) Listing

1.2.1 Brough Reservoir

The beneficial uses defined by the State of Utah for Brough Reservoir are: 2B (secondary contact recreation), 3A (coldwater fishery), and 4 (agriculture) (Standards of Quality for Waters of the State §R317-2, UAC). Utah's Year 2000 303(d) list identified Brough Reservoir as being impaired due to exceedences of temperature and low dissolved oxygen, and removed the reservoir from the 303(d) list for total phosphorus exceedences due to a re-evaluation of new data. Utah's Year 2004 303(d) list also identified Brough Reservoir as being impaired due to exceedences of temperature and low dissolved oxygen, but indicated that a heat budget analysis determined that the temperature violations were caused by solar radiation. Therefore, because of this natural source of heat, the DWQ reported that site-specific temperature criteria should be developed for the reservoir.

Utah's Year 2006 303(d) list identified Brough Reservoir as being impaired due to low dissolved oxygen for cold water species of game fish and other aquatic life. The 2006 303(d) list also removed Brough Reservoir from the 303(d) list for temperature impairment. Therefore, Brough Reservoir requires the development of a TMDL due to low dissolved oxygen for its coldwater fishery beneficial use.

1.2.2 Red Fleet Reservoir

The beneficial uses defined by the State of Utah (Standards of Quality for Waters of the State §R317-2, UAC) for Red Fleet Reservoir are: 1C (Protected for domestic purposes with prior treatment), 2A (primary contact recreation), 2B (secondary contact recreation), 3A (coldwater fishery), and 4 (agriculture). Utah's Year 2000 303(d) list identified Red Fleet Reservoir as being impaired due to exceedences of temperature and low dissolved oxygen for beneficial use 3A. Utah's Year 2004 303(d) list identified Red Fleet Reservoir as being impaired due to exceedences of temperature and low dissolved oxygen for beneficial use 3A, but indicates that a heat budget analysis determined that the temperature violations were caused by solar radiation; and therefore, because of this natural source of heat, the DWQ reported that site- specific temperature criteria should be developed for the reservoir.

The Utah 2006 303(d) list removed Red Fleet Reservoir from the 303(d) list for temperature impairment, and identified Red Fleet Reservoir as being impaired due to low dissolved oxygen for beneficial use 3A.

1.2.3 Steinaker Reservoir

The beneficial uses defined by the State of Utah (Standards of Quality for Waters of the State §R317-2, UAC) for Steinaker Reservoir are: 1C (Protected for domestic purposes with prior treatment), 2A (primary contact recreation), 2B (secondary contact recreation), 3A (coldwater fishery), and 4 (agriculture). Utah's Year 2000 303(d) list identified Steinaker Reservoir as being impaired due to exceedences of temperature for beneficial use 3A. Utah's Year 2004 303(d) list identified Steinaker Reservoir as being impaired due to exceedences of temperature and low dissolved oxygen for beneficial use 3A, but indicates that a heat budget analysis determined that the temperature violations were caused by solar radiation; and therefore, because of this natural source of heat, the DWQ reported that site-specific temperature criteria should be developed for the reservoir. The Utah 2006 303(d) list removed Steinaker Reservoir from the 303(d) list for temperature impairment. Due to a typographical error, Steinaker Reservoir is not listed in Utah's Year 2006 303(d) list (Carl Adams - DWQ, pers. comm. 2007). In addition to designated beneficial uses, Ashley Creek and tributaries, from Steinaker diversion to headwaters are designated by the State as Category 1 High Quality Waters (Standards of Quality for Waters of the State §R317-2, UAC).

2.0 PROJECT AREA

2.1 Brough Reservoir

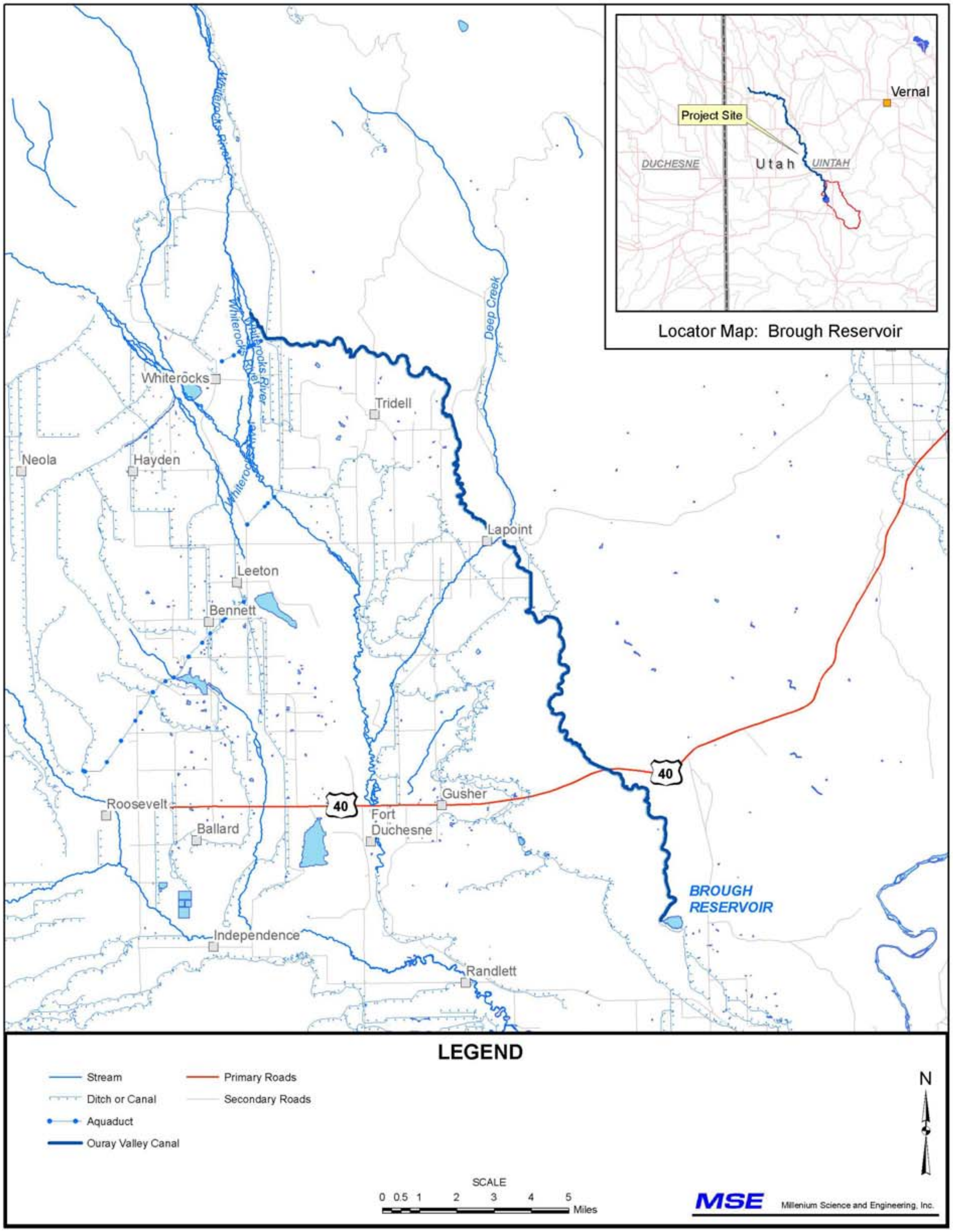
2.1.1 Location

Brough Reservoir is located in the Lower Green - Diamond Watershed, Hydrologic Unit Code (HUC) 14060001 as an off-stream impoundment in the Uinta Basin 16 miles southwest of Vernal, Utah. The reservoir was constructed to store and deliver water for irrigation. Water is diverted from the Whiterocks River into the Whiterocks and Ouray Valley Canal that becomes the Ouray Valley Canal near La Point, Utah, 17 miles northeast of the reservoir.

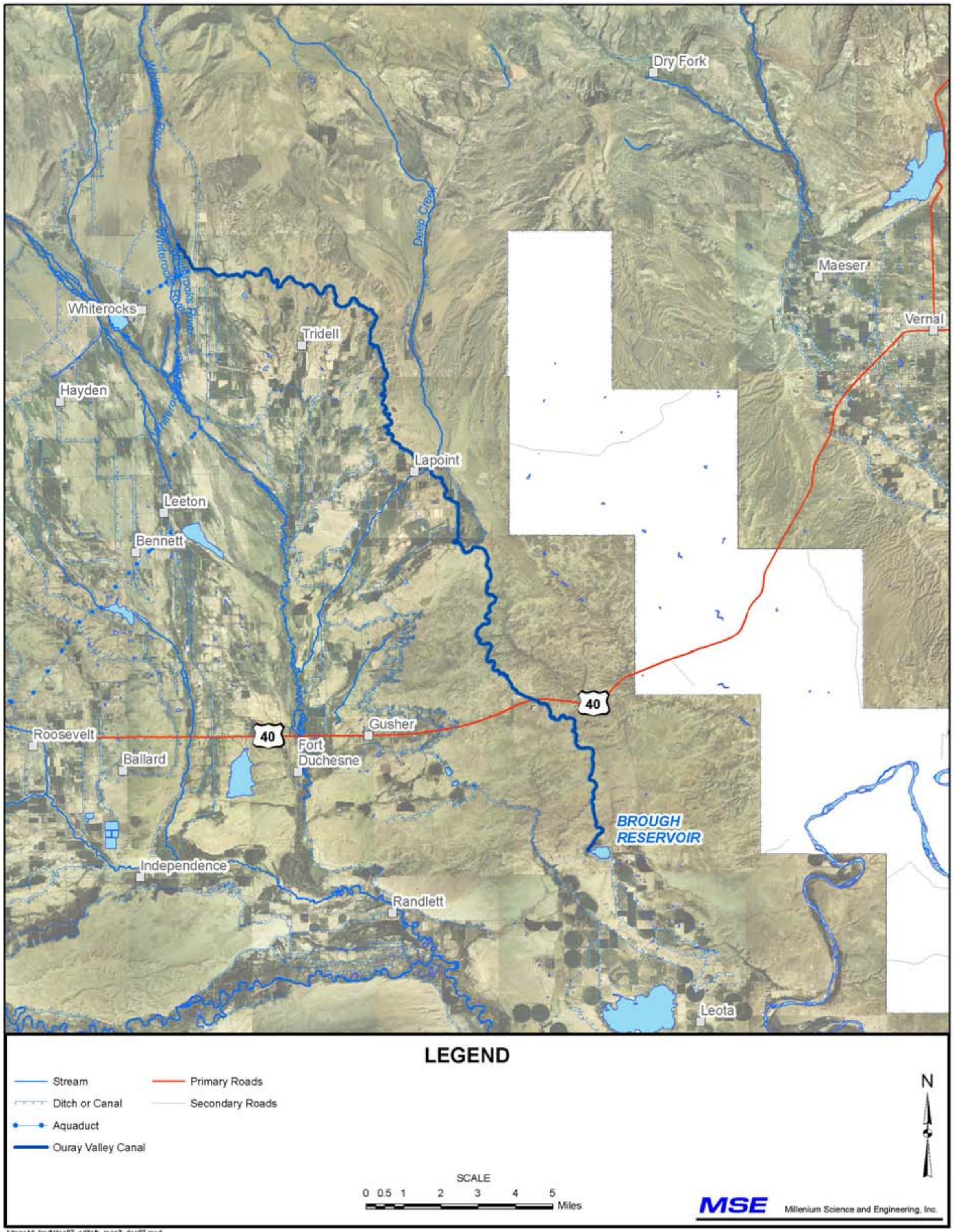
Five miles downstream from the diversion from the Whiterocks River, canal water flows over the Merkley drop; approximately a 300-foot fall over unconsolidated materials that contributes a significant sediment load to the canal.

The total canal flow distance from the Whiterocks River diversion to Brough Reservoir is 29 miles. For this report the 29 miles of canal to Brough Reservoir is simply referred to as the Ouray Valley Canal. An overview of the Ouray Valley Canal and Brough Reservoir is presented on Map 1. The areas that contribute flows to the Ouray Valley Canal were estimated by development of a catchment area. The methods used to develop the catchment area are described in Section 2.1.5.

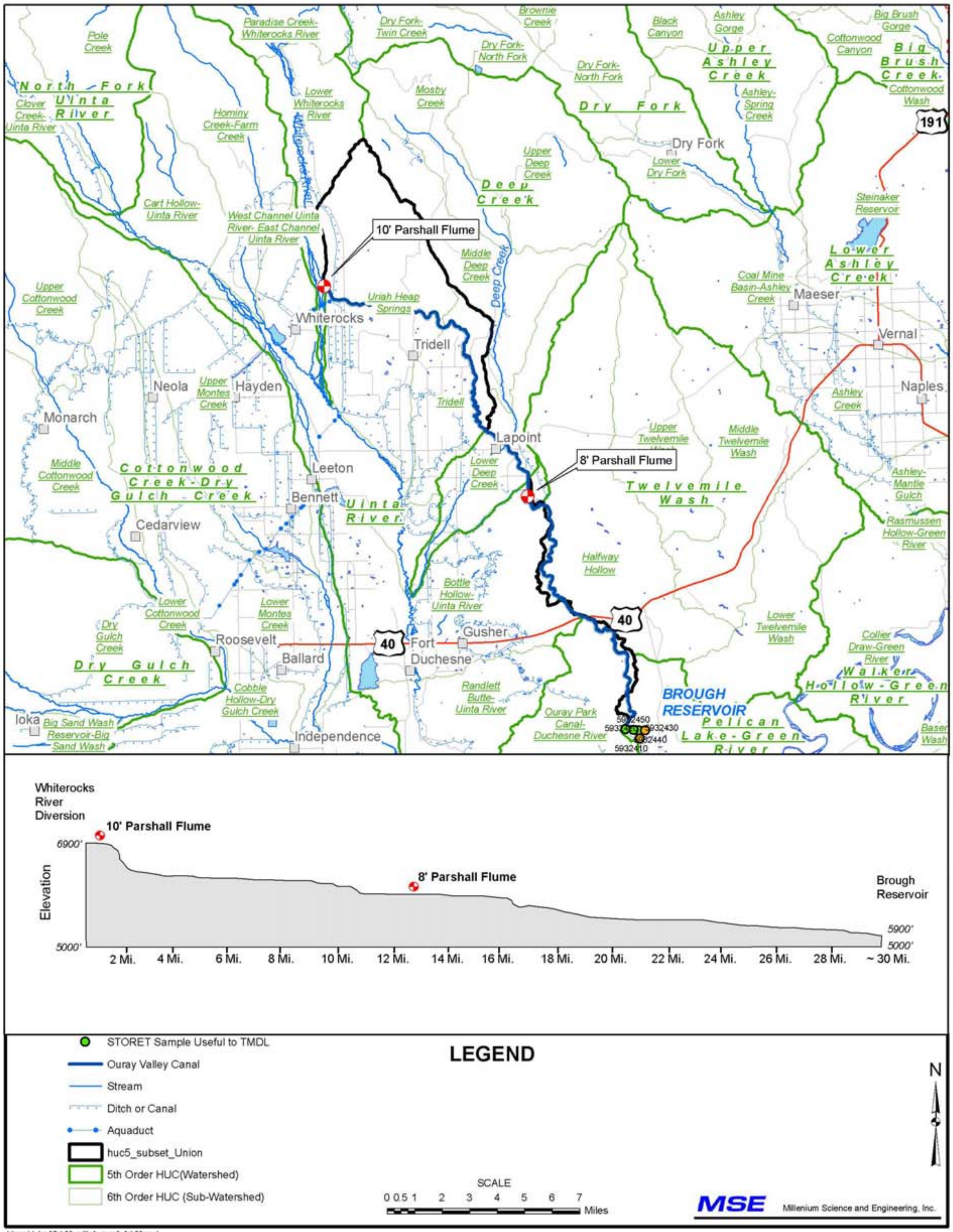
An aerial photograph showing Brough Reservoir developed by the National Agriculture Imagery Program (NAIP) is shown in Map 2. The surrounding hydrologic units and the Ouray Valley canal are shown on Map 3.



Map 1 Brough Reservoir - Location



Map 2 Brough Reservoir/Ouray Canal - NAIP Imagery



Map 3 Brough Reservoir/Ouray Canal - Hydrology

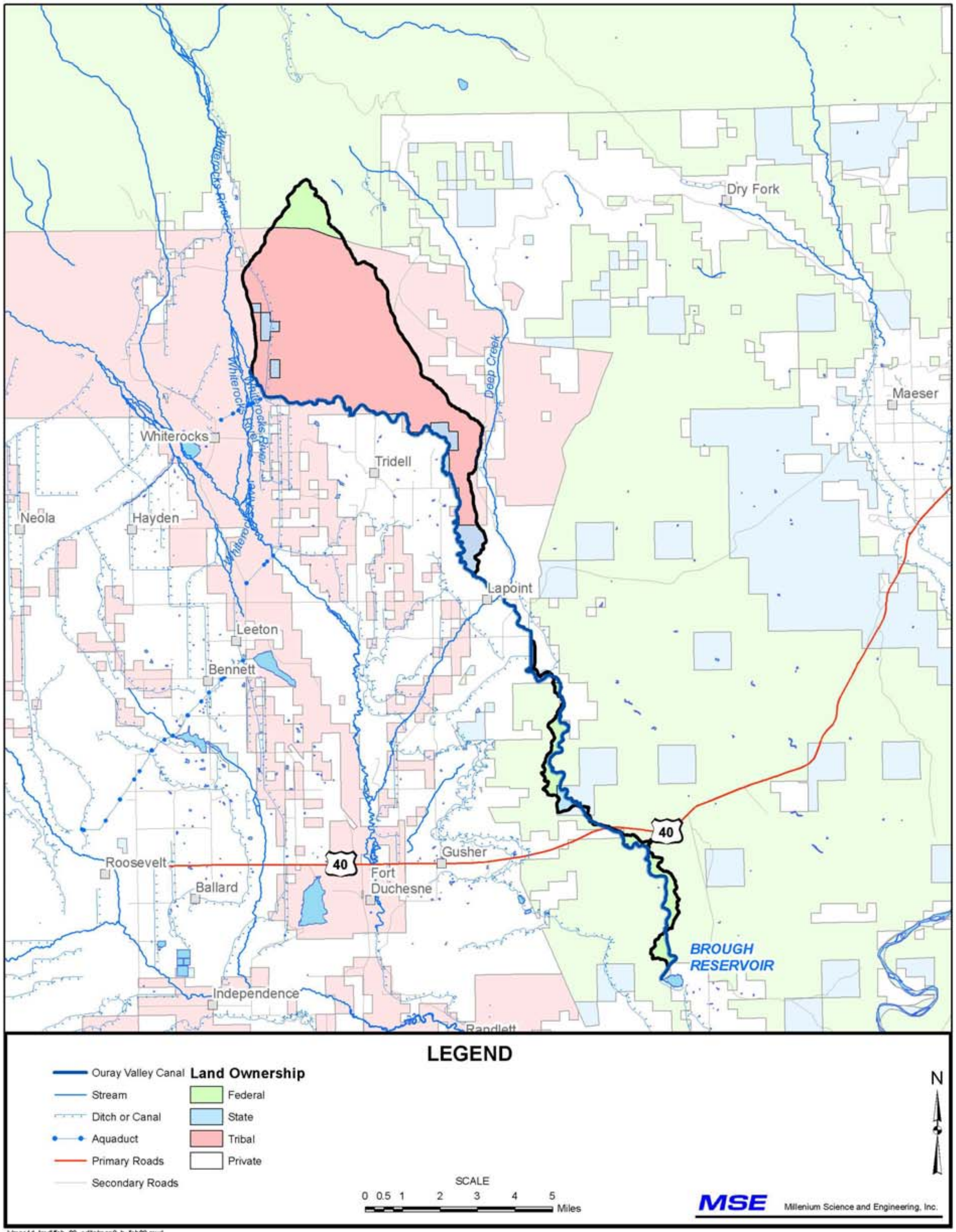
2.1.2 Land Ownership and Land Use/Cover

Map 4 and Map 5 show the land ownership and land use/cover near Brough Reservoir and the Ouray Valley Canal, respectively. Land ownership adjacent to the reservoir and up the Ouray Valley Canal is federally owned with some State Lands. Public access is unrestricted. Just north of La Point most land is privately owned, with Tribal lands of the Uintah and Ouray Reservation in the upper reaches of the catchment area. The percentage of federal, private and state owned lands in the catchment area are listed in Table 2.

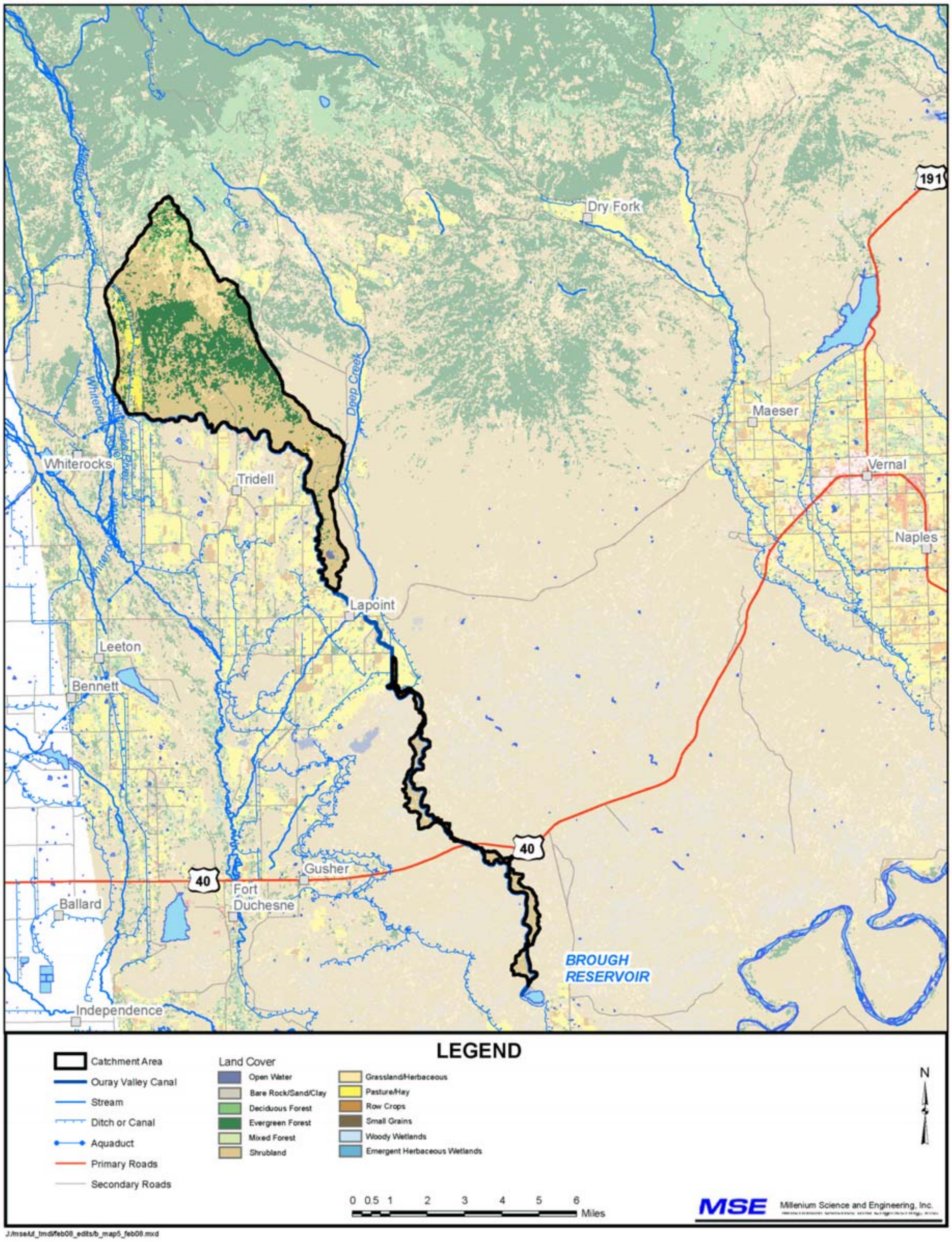
Table 2
Land Ownership in the Brough Reservoir Catchment Area

Land Ownership	Acres	Percent of Catchment Area
Federal	1,975	13%
Private	1,146	7%
State	155	1%
Tribal	12,510	79%
Total	15,787	100%

Land cover from Brough Reservoir and approximately 13 miles north along the Ouray Valley Canal is classified as shrublands. Near La Point the land use is a mixture of shrublands and pasture/hay. Shrublands account for 50% of the land cover in the catchment area and evergreen forest 30%. Grasslands account for 7% of the catchment area and pasture/hay 4%. Other land uses/cover total less than 1% of the land use/cover in the catchment area.



Map 4 Brough Reservoir/Ouray Valley Canal - Land Ownership



Map 5 Brough Reservoir/Ouray Valley Canal - Land Use/Land Cover

2.1.3 Geology and Soils

Brough Reservoir is at 5,010 feet above sea level with gentle slopes and hills adjacent to its shorelines. The topography along the Ouray Valley Canal consists of low terraces, fans, and desert valley plains. The high point near Brough Reservoir and the Ouray Valley Canal is an unnamed peak 12,666 ft above sea level forming a complex slope of approximately 3.5% to the reservoir, while the gradient of the Ouray valley Canal is 1%. The topography near Brough Reservoir and the Ouray Valley Canal is shown on Map 6.

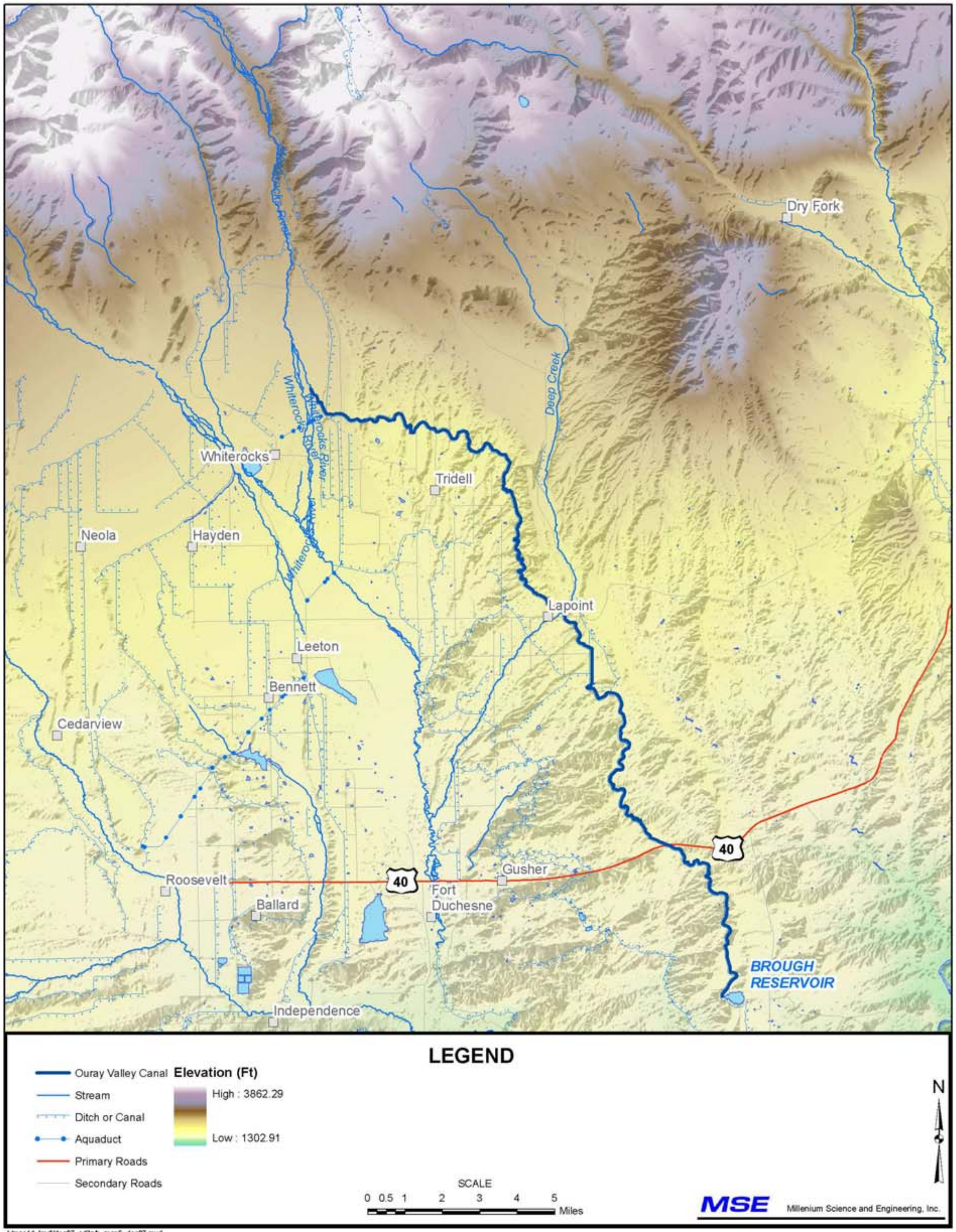
Few rock outcrops are present near Brough Reservoir. The geology adjacent to the reservoir consists of mixed alluvium, colluvium, and eolian deposits. The geology upstream of the reservoir and along the Ouray Valley Canal to LaPoint is mostly sandstone and siltstone with minor amounts of mudstone and conglomerate of the Brennan Basin Member of Duchesne River Formation. The basal part of this member intertongues with underlying mudstones of the Uinta Formation. Upstream of LaPoint and along the Ouray Valley Canal the geology consists of slope-forming siltstone and mudstone with ledge-forming thin-bedded sandstone of the Dry Gulch Member of Duchesne River Formation. Further upstream to the Whiterocks diversion, the canal is situated in fine-grained sandstone, siltstone, and mudstone that contain abundant bentonite beds of the LaPoint Member of Duchesne River Formation.

The geology near Brough Reservoir and adjacent to the Ouray Valley Canal is shown on Map 7. The primary geologic units and occurrence in the catchment area are summarized in Table 3.

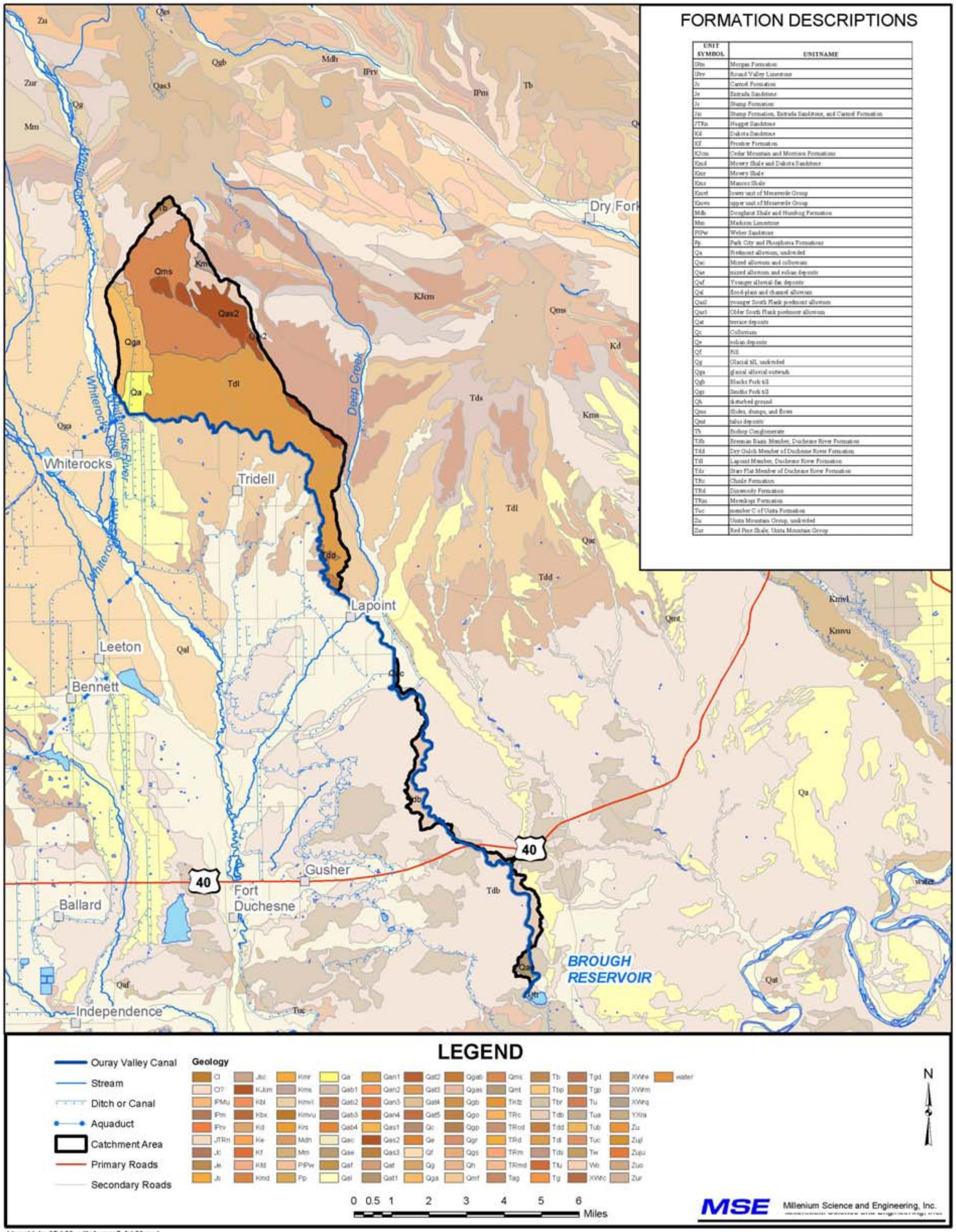
Table 3
Geologic Units in the Brough Reservoir Catchment Area

Unit Name	Acres	Percentage
Lapoint Member, Duchesne River Formation	6,332	44%
Slides, slumps, and flows	3,505	24%
Brennan Basin Member, Duchesne River Formation	2,176	15%
Bishop Conglomerate	113	1%
Mancos Shale	115	1%
Mixed alluvium and colluvium	62	0.4%
glacial alluvial outwash	1,264	9%
Piedmont alluvium, undivided	457	3%
Dry Gulch Member of Duchesne River Formation	166	1%
mixed alluvium and eolian deposits	174	1%
disturbed ground	0.3	0.002%

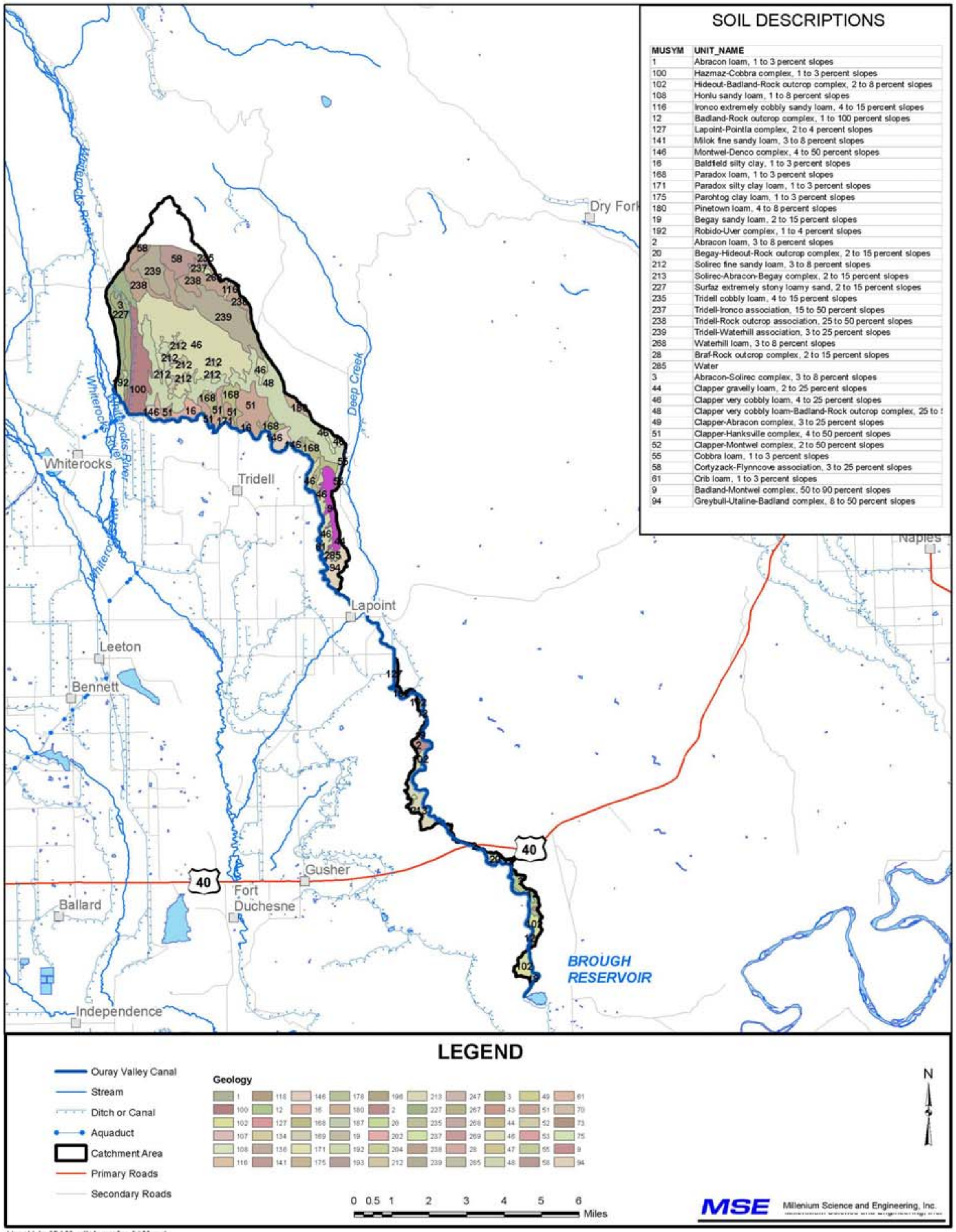
Soils near Brough Reservoir are sandy clays to gravelly sand having low to high erodibility, and well to somewhat excessive drainage and permeability. Available soils data were obtained from SURGO (Map 8) and STATSGO (Map 9). Taxonomic descriptions of the soils available in the STATSGO database for the Brough Reservoir catchment area are listed in Table 4.



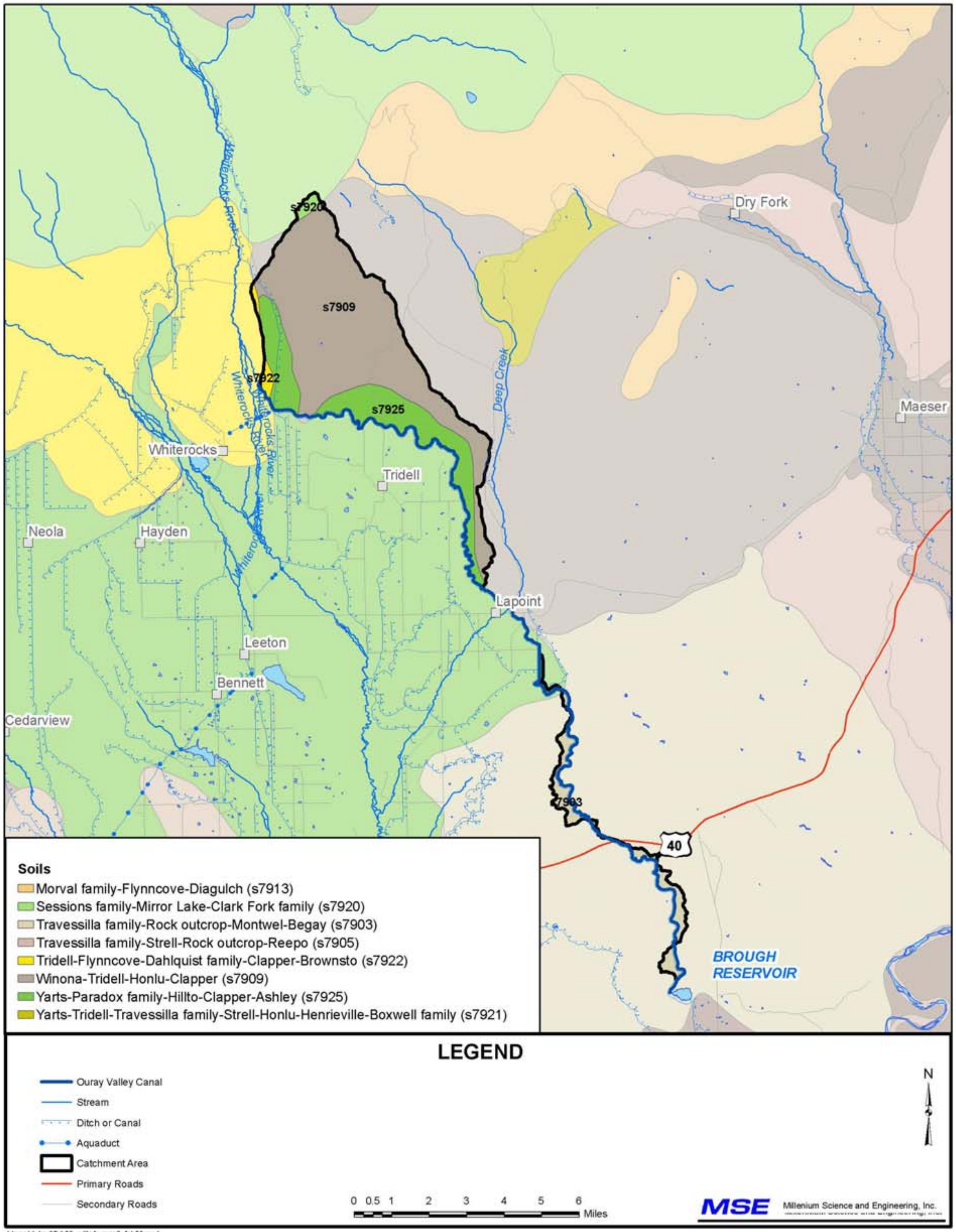
Map 6 Brough Reservoir/Ouray Valley Canal - General Topography



Map 7 Brough Reservoir/Ouray Valley Canal – Geology



Map 8 Brough Reservoir/Ouray Valley Canal – Soils (SURGO)



Map 9 Brough Reservoir/Ouray Valley Canal – Soils (STATSGO)

Table 4
STATSGO Soil Taxonomic Classifications in the Brough Reservoir Catchment Area

SOIL NAME	TAXONOMIC CLASSIFICATION
Ashley	USTIC TORRIFLUVENTS, COARSE-LOAMY OVER FRAGMENTAL, MIXED (CALCAREOUS), MESIC
Begay	USTOLLIC CAMBORTHIDS, COARSE-LOAMY, MIXED, MESIC
Boxwell family	ARIDIC HAPLOBOROLLS, FINE-LOAMY, MIXED
Brownsto	BOROLLIC CALCIORTHIDS, LOAMY-SKELETAL, MIXED
Clapper	USTOLLIC CALCIORTHIDS, LOAMY-SKELETAL, MIXED, MESIC
Clark Fork family	TYPIC USTORTHENTS, SANDY-SKELETAL, MIXED, FRIGID
Dahlquist family	BOROLLIC HAPLARGIDS, LOAMY-SKELETAL, MIXED
Diagulch	ARIDIC HAPLOBOROLLS, FINE-LOAMY, MIXED
Flynncove	ARIDIC ARGIBOROLLS, LOAMY-SKELETAL, MIXED
Henrieville	USTIC TORRIORTHENTS, COARSE-LOAMY, MIXED (CALCAREOUS), MESIC
Hillto	USTOLLIC PALEORTHIDS, LOAMY-SKELETAL, MIXED, FRIGID
Honlu	USTOLLIC CALCIORTHIDS, FINE-LOAMY, MIXED, MESIC
Mirror Lake	TYPIC CRYORTHENTS, SANDY-SKELETAL, MIXED
Montwel	TYPIC TORRIORTHENTS, FINE-LOAMY, MIXED (CALCAREOUS), MESIC
Morval family	ARIDIC ARGIBOROLLS, FINE-LOAMY, MIXED
Paradox family	USTIC TORRIORTHENTS, FINE-LOAMY, MIXED (CALCAREOUS), MESIC
Reepo	USTIC TORRIPSAMMENTS, MIXED, MESIC
Sessions family	ARGIC CRYOBOROLLS, FINE, MONTMORILLONITIC
Strell	LITHIC USTIPSAMMENTS, MIXED, FRIGID
Travessilla family	LITHIC USTIC TORRIORTHENTS, LOAMY, MIXED (CALCAREOUS), MESIC
Tridell	ARIDIC CALCIBOROLLS, LOAMY-SKELETAL, MIXED
Winona	LITHIC USTOLLIC CALCIORTHIDS, LOAMY-SKELETAL, CARBONATIC, MESIC
Yarts	USTIC TORRIORTHENTS, COARSE-LOAMY, MIXED (CALCAREOUS), MESIC

2.1.4 Climate

The Western Regional Climate Center (WRC) operated by the Desert Research Institute (Reno, Nevada) acts as a clearinghouse for the National Climatic Data Center and the State Climate Offices. Data is available on the Internet from the WRC at http://www.wrcc.dri.edu/.

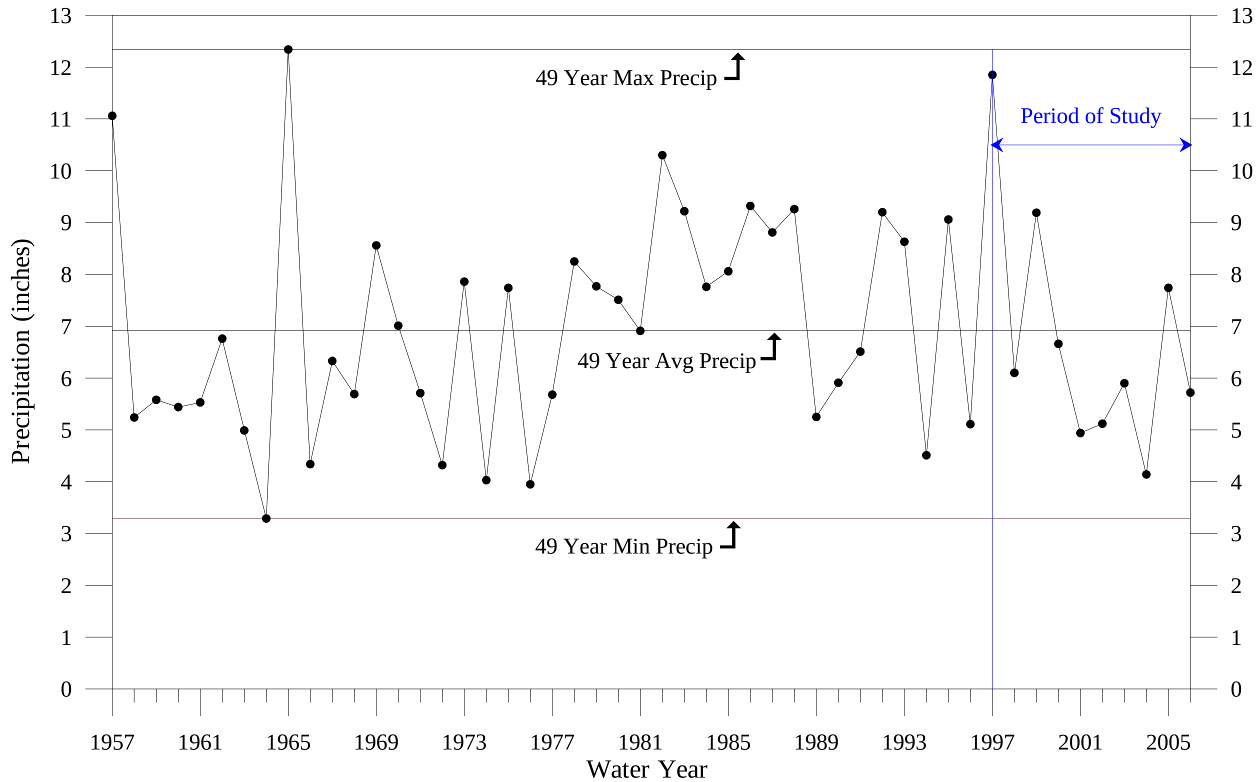
For this water quality study, there are three climate stations located near Bough Reservoir and the Ouray Valley Canal. These climate stations are located in La Point, Fort Duchesne, and Ouray, Utah. Among these stations the most complete climate record is from the station located in Ouray, Utah. This climate station is identified as "Ouray 4 NE, Utah (426568)" and is located approximately 8 miles south of Brough Reservoir.

The period of record for the Ouray 4 NE station is from 1956 to 2006. A climate summary for the Ouray 4 NE, Utah (426568) station is included in **Error! Reference source not found.**.

At the Ouray 4NE climate station the 51 year average annual precipitation was 6.9 inches with average annual snowfall of 15.2 inches, with average maximum temperature of 63.9° F and an average minimum temperature of 31.4° F.

Precipitation data from the Ouray 4NE climate station were totaled for the water years (October 1 through September 30) 1957 to 2006. For these water years the maximum precipitation was 12.3 inches, the minimum was 3.3 inches and the average was 6.9 inches (see Figure 1).

Figure 1
OURAY 4 NE, Utah (426568) Climate Station
1957 - 2006 Water Year - Total Precipitation



As shown in Figure 1, the last ten water years at the Ouray 4NE climate station include approximate maximum precipitation (12 inches in 1997) and minimum precipitation (4 inches in 2004) events and represent wet and dry years in the area for the 49-year period of record. As such, this 10-year period is an appropriate period of study to include the observed range of data variation through wet and dry years.

Therefore, to include the seasonality of data through wet and dry years, the appropriate period of study for the Brough Reservoir water quality study and TMDL is October 1, 1996 to September 30, 2006 (the 1997 water year is from October 1, 1996 through September 30, 1997). Data evaluation for the Brough Reservoir water quality study and TMDL will be limited to data (e.g., water quality and flow) available since October 1, 1996.

2.1.5 Watershed Hydrology

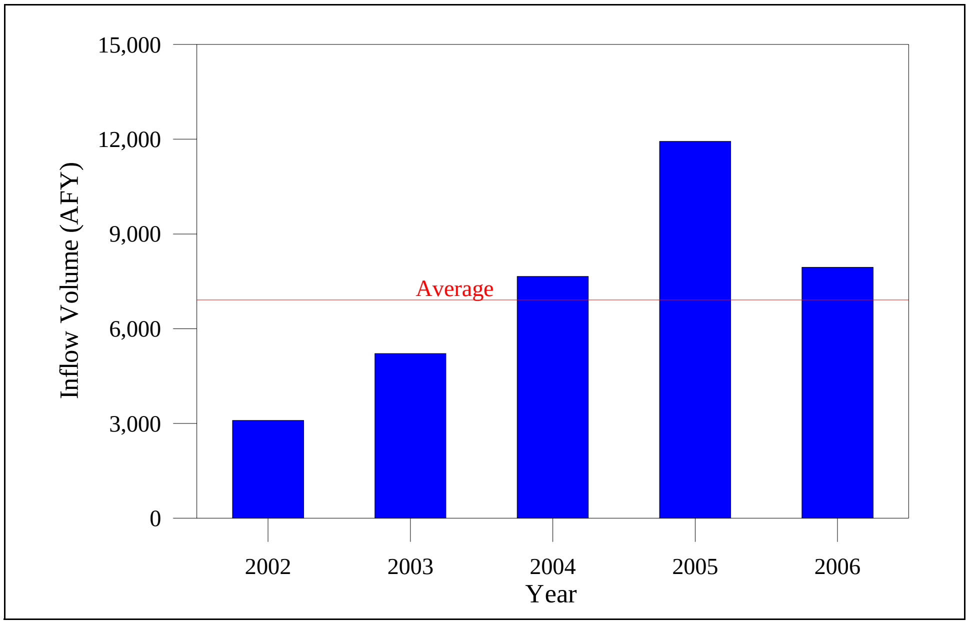
The Ouray Valley Canal transports irrigation water from the Whiterocks River 29 miles to Brough Reservoir. The headwaters of the Whiterocks River are in the High Uinta mountains with the highest point at approximately 12,666 feet.

There are two stream gage stations located on the canal between Whiterocks River and Brough Reservoir: a 10-foot Parshall Flume near the Whiterocks River diversion, and an 8-foot Parshall Flume on the Ouray Valley Canal (Map 3).

Map 3 identifies Brough Reservoir, the surrounding 5th and 6th order HUCs, and the main tributary to the reservoir - Ouray Valley Canal. As a non-natural waterway, the Ouray Canal crosses seven 6th order HUCs. Therefore, a modified approach to typical watershed delineation and analysis is required. As discussed in Section 2.1.1, the areas that contribute flows to the Ouray Valley Canal were estimated by development of a catchment area. The catchment area was derived by using the existing sub-watershed boundaries and the Ouray Valley Canal (captured from the hydrologic dataset downloaded from the State Geographic Information Database [SGID], obtained from the Utah Automated Geographic Reference Center [AGRC]). In places where the Ouray Valley Canal cuts across hydrologic units, those areas "updrainage" were captured from the edge of the hydrologic unit down to the Ouray Valley Canal. In addition, because Deep Creek does not flow into the Ouray Valley Canal, portions of the Deep Creek hydrologic unit were excluded from the catchment area. The resulting catchment area for the Ouray Valley Canal is shown on Map 2. The Brough Reservoir catchment area encompasses 15,786 acres.

Flow data at the Parshall flumes are collected and managed by the River Commissioner and available on-line from the Utah Division of Water Rights. Mean daily flow records for the period of study from these two gages are presented in **Error! Reference source not found.**. Variation in the inflow for water years 2002 to 2006 are shown in Figure 2.

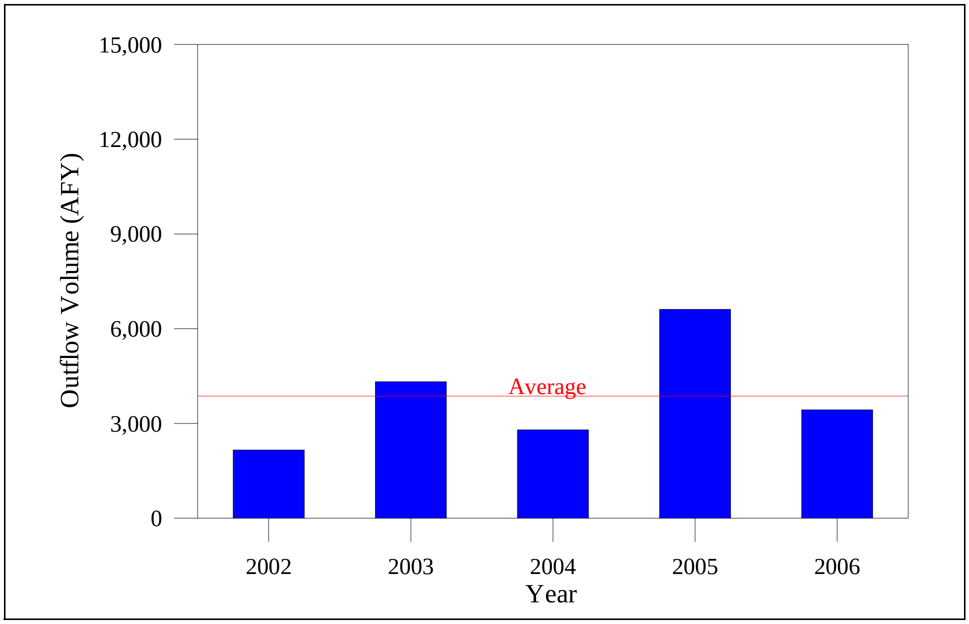
Figure 2
Annual Variation in Brough Reservoir Inflow



Inflows are measured at a Parshall flume located on the Ouray Valley Canal 10 miles upstream from Brough Reservoir; therefore significant losses are expected.

Out flows and reservoir elevation data were provided by the Ouray Park Irrigation Company. The irrigation company provided annual water release data for Brough Reservoir for years 2002 through 2006. These data are provided in **Error! Reference source not found.** (note the data provided are titled "Inflows and Outflows", but are general quantitative and qualitative reservoir water level elevation recordings). Daily outflow measurements were not available for Brough. The average outflow for the period was 3,865 acre-feet per year (AFY), based on water rights releases recorded by the Ouray Park Irrigation Company. Variation in the releases (outflow) for years 2002 to 2006 are shown in Figure 3.

Figure 3
Annual Variation in Brough Reservoir Outflow



A coarse water budget was calculated for Brough Reservoir, based upon inflow and outflow measurements provided by the Ouray Park Irrigation Company. The water budget compares sources of water to the reservoir to ways in which water is lost. The budget can be summarized as:

Sources		Losses
Tributary + Precipitation	=	Reservoir Releases - Evaporation +/- Unmeasured Sources

The primary sources of water to Brough Reservoir are inflow from the Ouray Valley Canal and precipitation. Primary losses are via outflow and evaporation.

The water budget was determined by calculating measured values for each component for the available data period January 1, 2002 through December 31, 2006. The average inflow was 9.54 cfs for this period (6,913 AFY). A precipitation of 6.9 in/yr was specified, based upon the climate station identified as "Ouray 4 NE, Utah (426568)" located approximately eight miles south of Brough Reservoir. This precipitation value corresponds to an annual water gain of 74 AFY, after multiplying precipitation rate (6.9 in/yr) by the surface area of the reservoir (128 acres).

An evaporation rate of 35 inches per year was specified, based upon data from Vernal Airport, the nearest weather station with available data. This evaporation rate corresponds to an annual water loss of 373 AFY, after multiplying evaporation rate (35 in/yr) by the surface area of the reservoir. A summary of the water budget is shown below in Table 5. Unmeasured losses account for 39.3% of the overall water budget. These losses may be due to loss in the Ouray Valley Canal between the reservoir and the Parshall flume located 14 miles upstream from the reservoir, losses to groundwater beneath the reservoir, or a higher evaporation rate.

Table 5
Water Budget for Brough Reservoir

Sources	Flow (AFY)
Ouray Valley Canal	6,911
Precipitation	74
Losses	
Outflow	3,865
Evaporation	373
Unmeasured Losses	
Groundwater/Ungaged Flow*	-2,746

*Calculated to provide water balance

2.1.6 Fisheries

The Utah Division of Wildlife Resources manages Brough Reservoir as a put-and-take sport fishery and gained status as a Blue Ribbon Fishery in 2007 based on productivity, forage availability and good fish growth. The reservoir is stocked in lower densities with Uintah Rainbow Trout annually in the spring. A small population of Uintah Brown Trout was added in 2005 and 2006 (Table 6). A gill net survey conducted in May, 2003 yielded a catch rate of 0.46 rainbow trout per net hour, a mean length of 327 mm, mean weight of 481 g, condition factor of 1.37 and fat index of 1.8.

Table 6
Brough Reservoir Trout Stocking

TYPE	DATE	NUMBER	SIZE (IN)
Uintah Rainbow Trout	May, 2007	3927	4.23
Uintah Rainbow Trout	May, 2007	1020	9.93
Uintah Rainbow Trout	April, 2006	1450	9.11
Uintah Rainbow Trout	April, 2006	1450	9.11
Uintah Rainbow Trout	April, 2006	2059	9.11
Uintah Rainbow Trout	April, 2006	4508	4.77
Uintah Brown Trout	July, 2006	1104	4.79
Uintah Brown Trout	May, 2005	1118	5.21
Uintah Rainbow Trout	May, 2005	4538	5.33
Uintah Rainbow Trout	May, 2004	1890	9.75
Uintah Rainbow Trout	May, 2004	1530	9.41

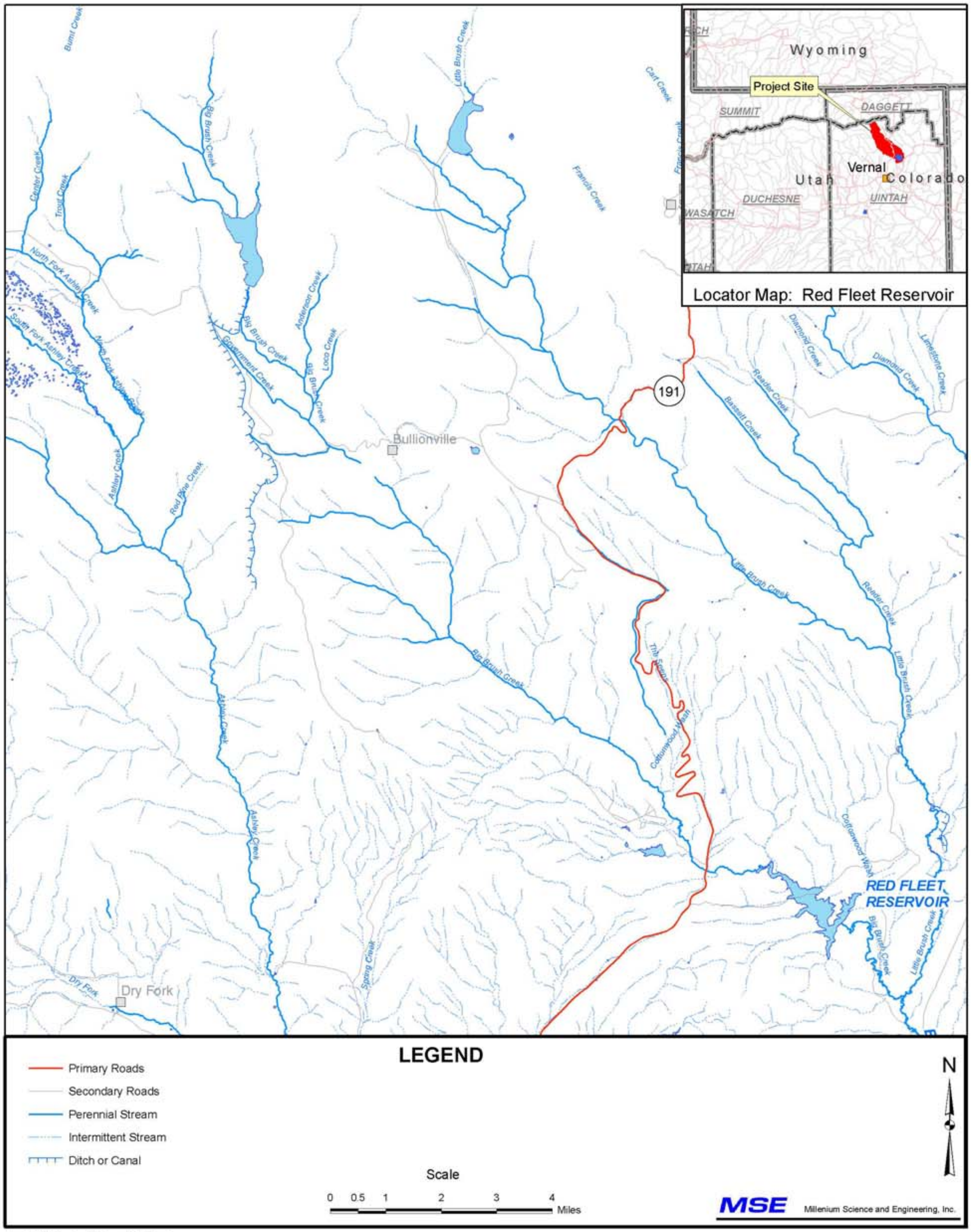
2.2 Red Fleet Reservoir

2.2.1 Location

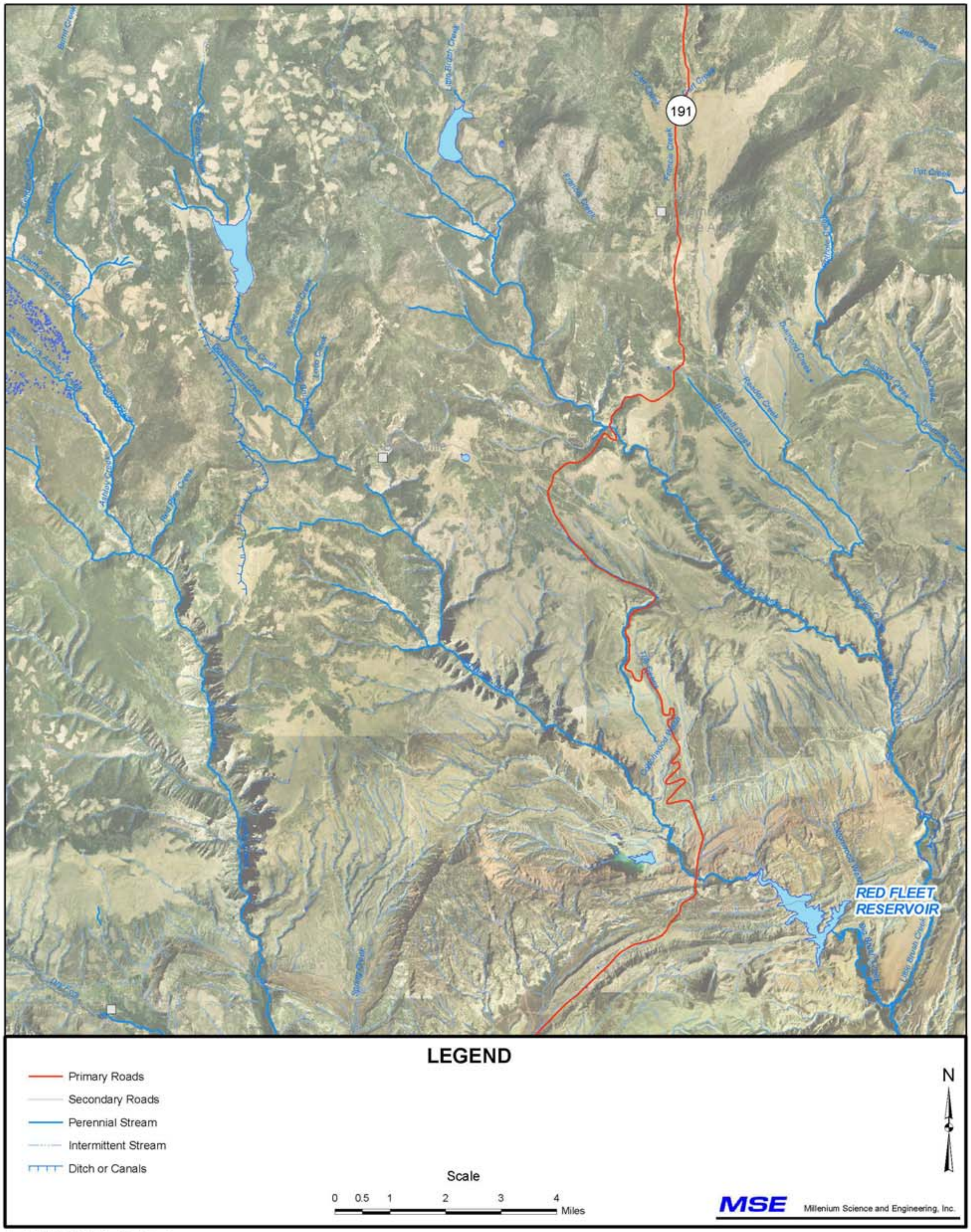
Red Fleet Reservoir is an impoundment on Big Brush Creek located 10 miles northeast of Vernal, Utah. The reservoir lies within the Uinta Basin Watershed Assessment Unit (UT-L-14060002-006). The reservoir is within the Ashley-Brush Watershed identified with 4th order (8-digit) Hydrologic Unit Code (HUC) – 14060002. Within the Ashley-Brush Watershed, Red Fleet Reservoir is situated in the Big Brush Creek and Cottonwood Wash sub-watersheds. The location of Red Fleet Reservoir is shown on Map 10.

The areas that contribute flows to Red Fleet Reservoir were estimated by development of a catchment area. The methods used to develop the catchment area are described in Section 2.2.5.

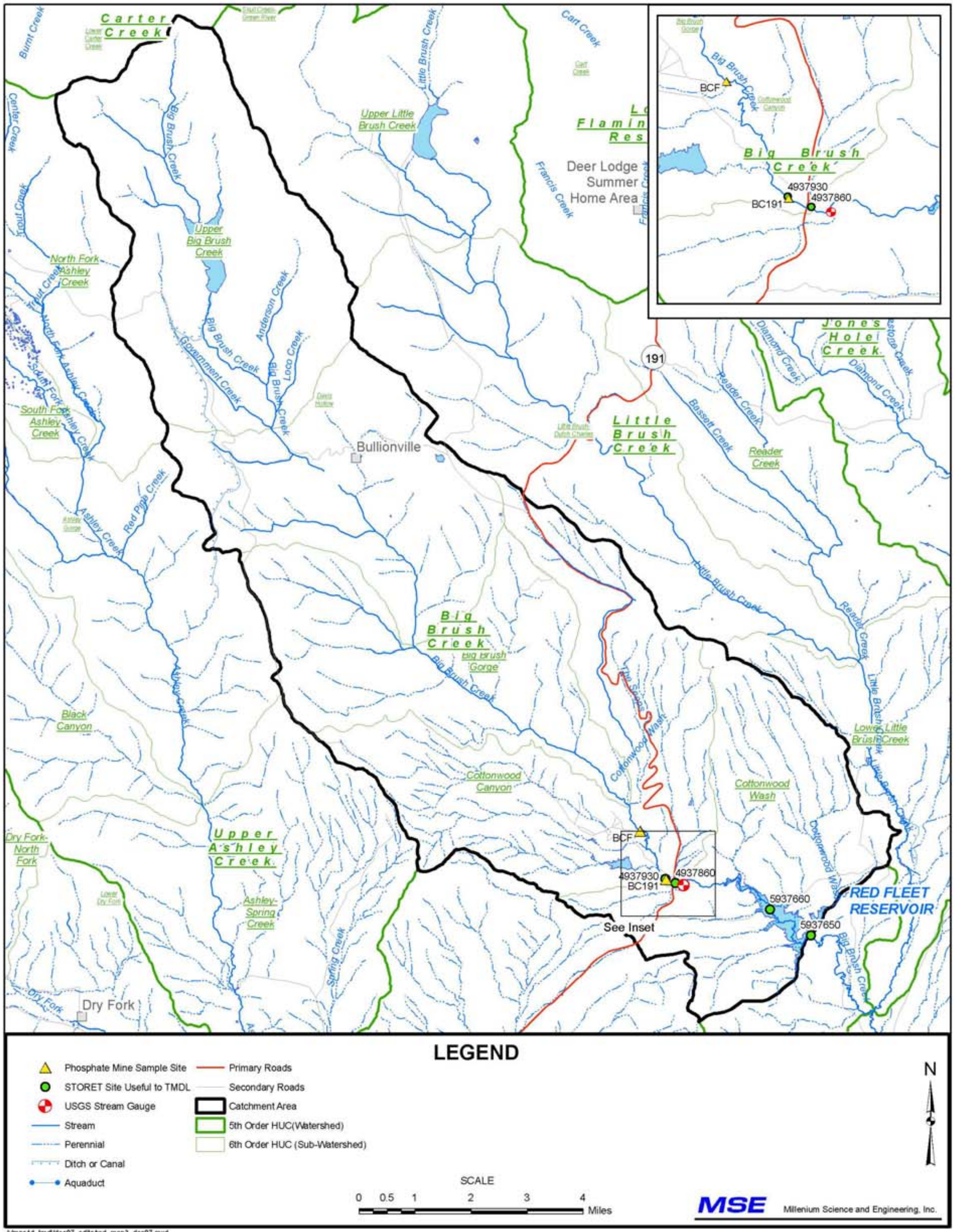
An aerial photograph developed by the National Agriculture Imagery Program (NAIP) showing Red Fleet Reservoir is provided on Map 11. The surrounding 5th and 6th order HUCs and the main tributary to the reservoir – Big Brush Creek - are shown on Map 12.



Map 10 Red Fleet Reservoir - Location



Map 11 Red Fleet Reservoir – NAIP Imagery



Map 12 Red Fleet Reservoir – Hydrology

2.2.2 Land Ownership and Land Use/Cover

Map 13 and Map 14 show the land ownership and land use/cover in the Red Fleet Reservoir catchment area, respectively. The lands adjacent to Red Fleet Reservoir are state owned. Land ownership northwest of the reservoir is privately owned and Industrial. The industrial land use in this area represents the Simplot Phosphate Mine. The total area of the Simplot Phosphate mine is 16,071 acres, with 11,823 acres within the catchment area.

The land from the Simplot Phosphate Mine to Oak Parks reservoir is federally owned (U.S. Forest Service). The percentages of federal, private, and state-owned lands in the catchment area are listed in Table 7.

Table 7
Land Ownership in the Red Fleet Reservoir Catchment Area

Land Ownership	Acres	Percent of Catchment Area
Federal	45,226	76%
Private (Simplot Mine)	12,030	19%
Private (other)	207	0.3%
State	2,571	4%
Total	59,827	100%

Simplot Phosphates, LLC operates a phosphate mine approximately 18 kilometers north of Vernal in Uinta County, Utah. The company mines roughly 2.3 million tons of ore annually. The company is capable of processing about 1.3 million tons of concentrate annually. The mine operates at a nearly constant annual rate because its product is used exclusively in its company-owned manufacturing facility (USGS, 1994). The mine was originally developed by the San Francisco Chemical Company in 1960. Chevron Resources Company purchased the mine in 1981, and in 1984 began construction of a slurry pipeline and the fertilizer manufacturing plant near Rock Springs, Wyoming. Chevron's fertilizer plant and pipeline were operational by 1986. In the Spring of 1992, the SF Phosphates Limited Company was formed with the purchase of the mine, pipeline, and fertilizer plant in a joint venture between the J.R. Simplot Company and Farmland Industries, Inc. In 2003, the J.R. Simplot Company purchased Farmland Industries' interest in the operation, renaming it Simplot Phosphates, LLC. Simplot Phosphates, LLC uses three key raw ingredients in the production of fertilizer: phosphate ore from the Vernal, Utah mine; sulfur, which is a by-product from Wyoming oil fields; and ammonia, which is made from natural gas and delivered to the Rock Springs manufacturing plant (Simplot website: http://simplot.com/company/upload/sim_phos.pdf).

The strip mining process involves topsoil removal and stockpiling, blasting and removal of 40 to 80 feet of overburden consisting of carbonate rock and shale. These materials are removed using D-11 bulldozers to an adjacent area to expose the ore. The ore layer, which is 17 to 20 feet thick in the mine, is drilled with 5.5-inch diameter holes on an 11 by 11 foot pattern and blasted with explosives. The broken up ore is loaded into 85-ton haul trucks using a 13 cubic yard excavator shovel. Haul trucks transport the ore to a crusher, which reduces particle size to less than 10 inches in diameter. Crushed ore is conveyed to a stockpile above a grinding mill. Mined areas are backfilled with overburden, recontoured, stabilized, and revegetated. The grinding mill further reduces particle size to less than 1 millimeter in diameter (SF Phosphates Limited Company Brochure).

Ground ore is pumped as a slurry through a 12-inch plastic pipe to the main concentrator building. Ore slurry is mixed with reagents and run through a flotation process to recover the phosphate mineral fraction. Material rejected from the initial flotation is processed through a secondary crushing and flotation circuit to remove unwanted material. The secondary concentrate is mixed with the primary concentrate and sent to a ball mill for final grinding. The concentration process increases phosphate content from 17 to 20 percent to about 31 percent. Unwanted material removed during concentration is directed to a tailings impoundment. Concentrated phosphate slurry is processed in a density separator to remove excess water. The slurry is then transported 145 kilometers by underground pipeline to a processing plant in Rock Springs, Wyoming. Three 2,000 horsepower pumps at the Vernal pump station and three identical pumps near the mid point of the pipeline are required to transport the slurry to its destination. In Rock Springs, the slurry is processed with sulfuric acid and mixed with ammonia and other chemicals to produce fertilizer for agricultural applications (SF Phosphates Limited Company Brochure).

A Draft Resource Management Plan and Draft Environmental Impact Statement (January 2005) prepared by the BLM Vernal Field Office states that:

> "The Utah Division of Water Quality regulates Simplot Phosphate's phosphate mining operation, including the large tailings pond disposal area. Samples of tailings water taken indicate concentrations of phosphate, fluoride, total dissolved solids (TDS), and chromium to have been higher than the Utah Water Quality Standards (UDDW, 2003). These standards are the most stringent of the applicable numeric criteria for the nearby Big Brush Creek. In 1996 Simplot (then SF Phosphates Ltd.) performed a full-spectrum chemical analysis on a grab sample of the mine's tailings water. With the available data, it is not possible to know if the standards for cyanide, chromium, or zinc exceeded limits because the testing methods did not meet the accuracy levels for those determinations; however, the results indicate that TDS and phosphorus exceeded the limits. Although analyses of tailings solids show that the 1996 tailings solids are non-toxic, non-acid-forming, and non-saline, data showed higher levels of sulfates, hardness, calcium, and TDS in tailings water than those found in Big Brush Creek. This indicates that should tailings water migrate past the seepage collection system into Big Brush Creek, the creek's water would be degraded."

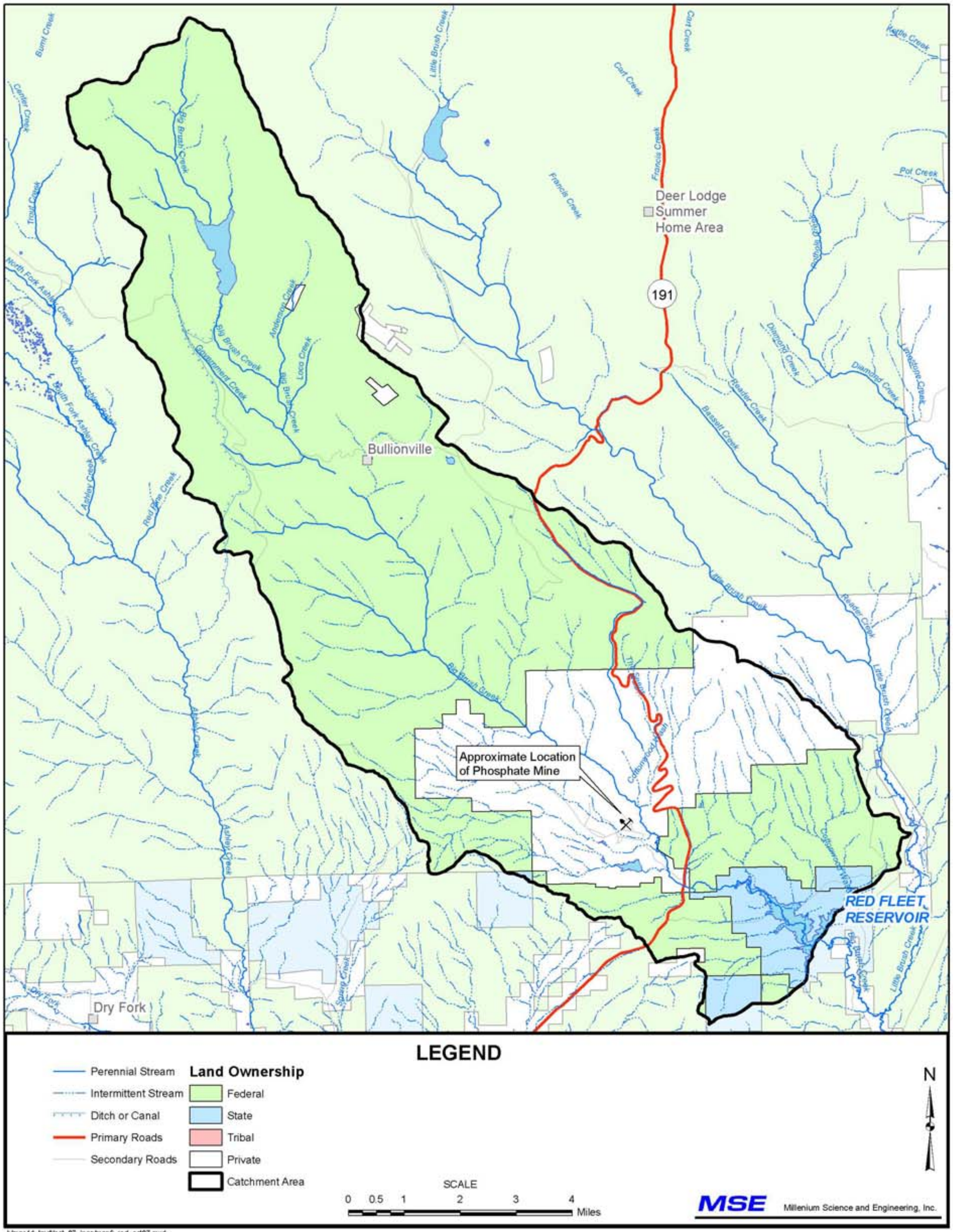
Phosphate mining on private land is expected to continue over the next 15 years (BLM, 2005a). Groundwater and surface water monitoring results for permit compliance are discussed in Section 4.2.1.

The lands adjacent to Red Fleet Reservoir are mapped as shrubland and grasslands with evergreen forest. Land northwest of the reservoir is also mapped as shrubland, grasslands, evergreen forest, with a small portion of pasture/hay. The land from the Simplot Phosphate Mine to Oak Parks reservoir mostly consists of evergreen and deciduous forest (Map 14).

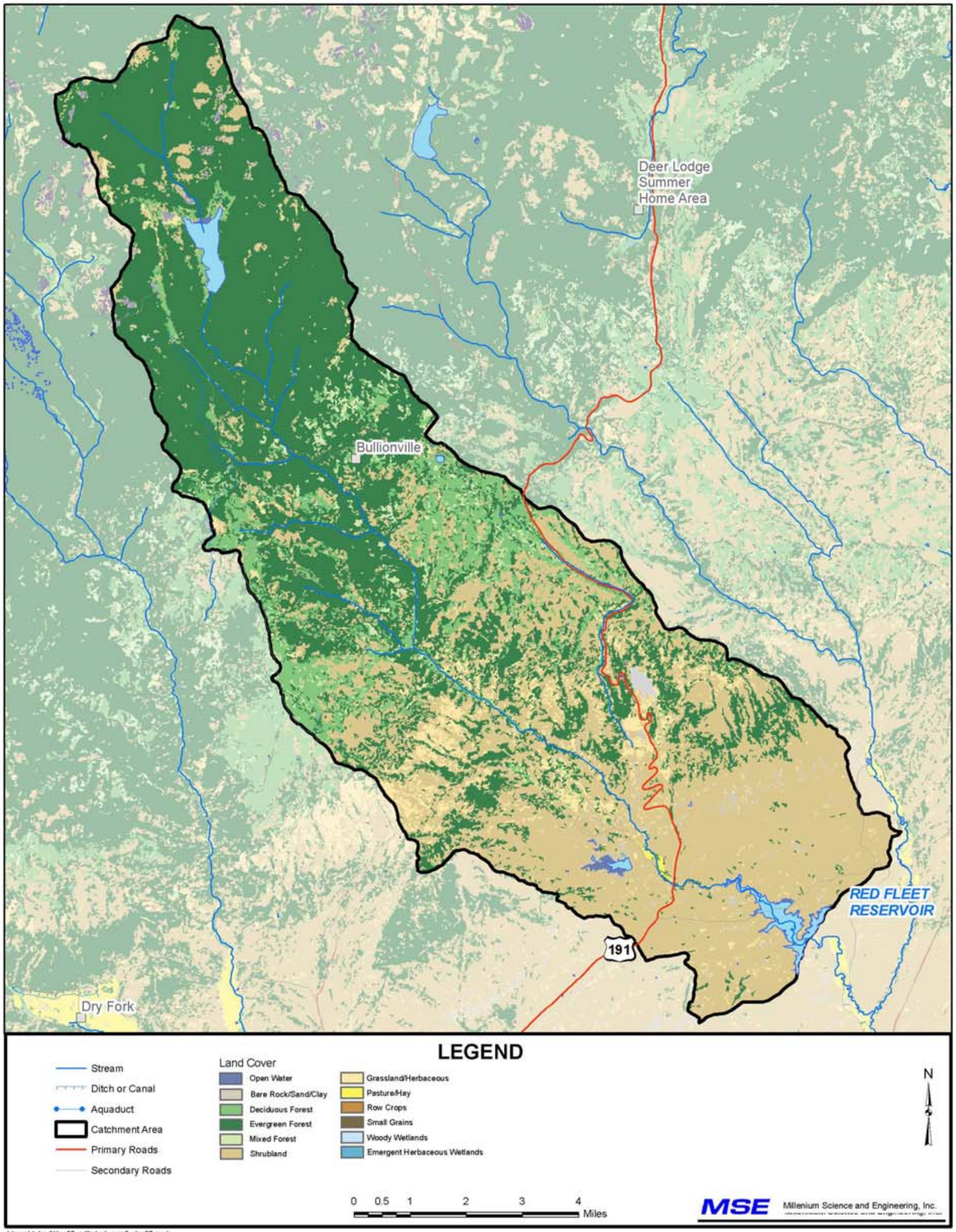
The acreage and percentage of various land cover types in the catchment area is listed in Table 8.

Table 8
Land Cover in the Red Fleet Reservoir Catchment Area

Land Cover	Acres	Percent
Evergreen Forest	120947	44.94%
Shrubland	101299	37.64%
Deciduous Forest	24188	8.99%
Grasslands/Herbaceous	10899	4.05%
Mixed Forest	4299	1.60%
Open Water	3442	1.28%
Bare Rock/Sand/Clay	2058	0.76%
Transitional	795	0.30%
Quarries/Strip Mines/Gravel Pits	421	0.16%
Commercial/Industrial/Transportation	406	0.15%
Pasture/Hay	200	0.07%
Emergent Herbaceous Wetlands	150	0.06%
Woody Wetlands	21	0.01%



Map 13 Red Fleet Reservoir – Land Ownership



Map 14 Red Fleet Reservoir – Land Use/Land Cover

2.2.3 Geology and Soils

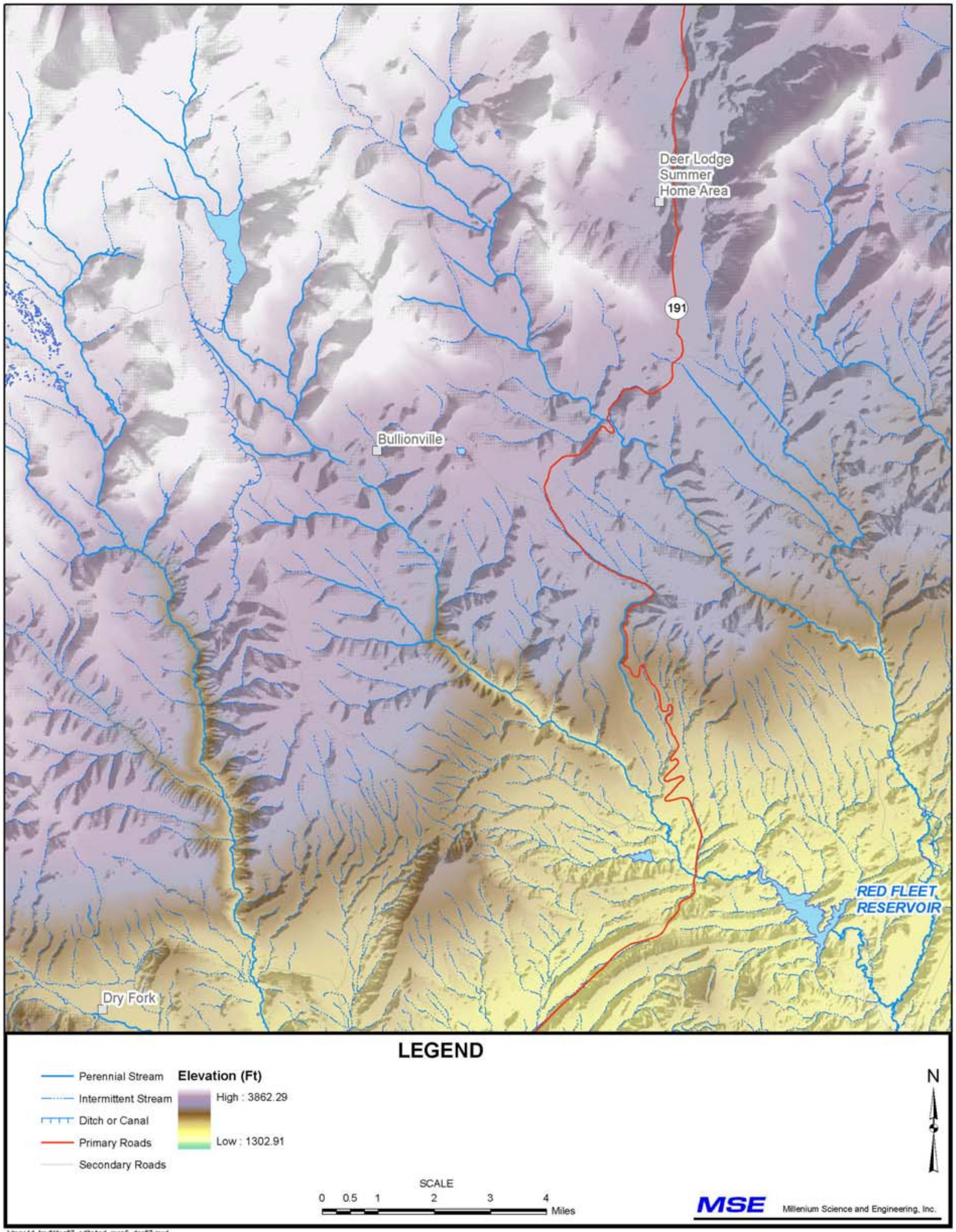
Red Fleet Reservoir is situated at 5,608 feet above sea level. The high point in the watershed is Trout Peak at 10,629 ft above sea level, developing a complex slope of 4.8% to the reservoir. The average gradient of Big Brush Creek is 3.8%. The topography near Red Fleet Reservoir and Big Brush Creek is shown on Map 15.

The geology near Red Fleet Reservoir is shown on Map 16. The geology adjacent to Red Fleet Reservoir consists of marine deposits (Stump and Carmel Formations, and Mowry Shale), sandstones (Entrada, Frontier, and Dakota Sandstones); and mixed alluvium, colluvium, and eolian deposits. Along the channel of Big Brush Creek up to Oak Park Reservoir the geology consists of Weber Sandstones. As Big Brush Creek flows through the south slope of the Uinta Mountains it is in contact with the Park City and Phosphoria Formations.

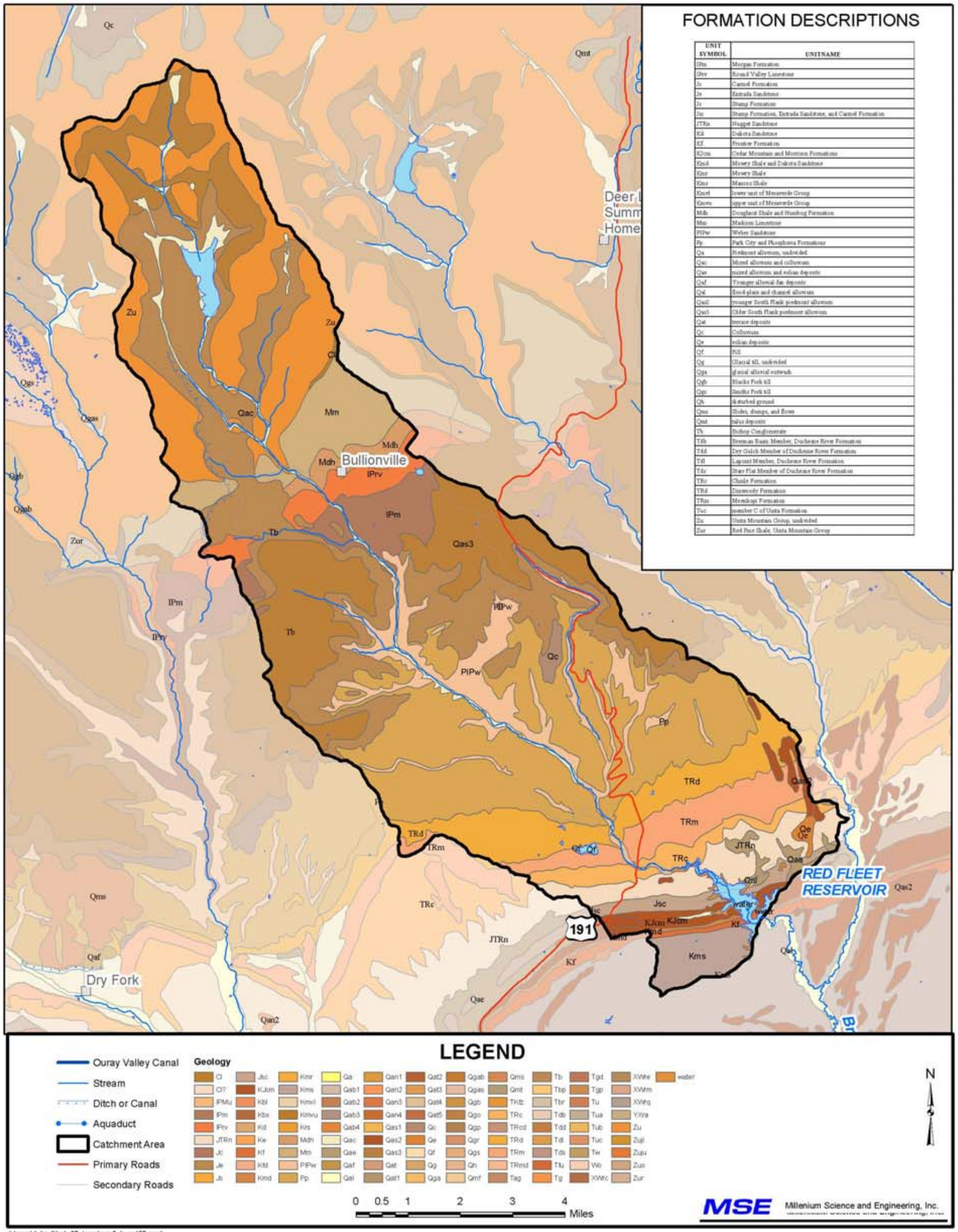
Phosphate deposits exist in the Uinta Basin within the Permian Park City Formation. The middle part of the formation, the Meade Peak Member, is the principal source of phosphate ore, which is present in the form of P_2O_5. This member is 10 to 90 feet thick in the western Uinta Mountains and thins to a feather edge near the Colorado State Line (BLM, 2005a). Phosphate-rich sediments, or phosphorite formed in a warm, shallow marine shelf environment where prolific marine life extracted and concentrated phosphate from upwelling ocean currents (Stokes, 1986). Extensive, relatively high-grade deposits occur at or near the surface, making phosphate mining economical because the ore can be cheaply strip-mined.

The total length of the Big Brush stream channel that passes through the Park City and Phosphoria formation is 32,257 feet. Of this total length, 4,826 feet (15%) come into direct contact with the formation. Approximately 20,282 feet (63%) of stream channel is within 500 feet of the formation, with the remaining 7,149 feet (22%) outside the 500 foot proximity.

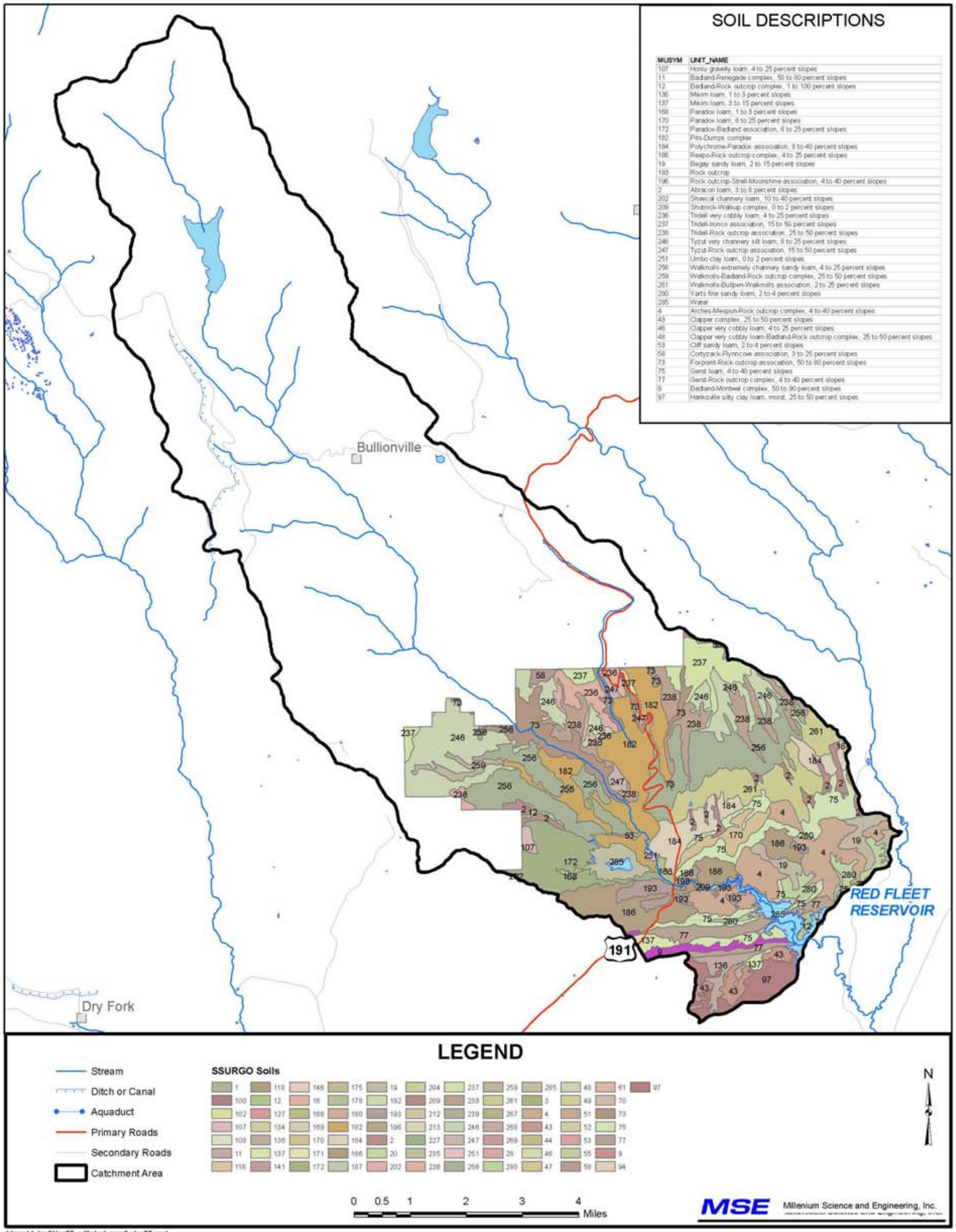
Available soils data in the Red Fleet Reservoir catchment area were obtained from SURGO (Map 17) and STATSGO (Map 18). Taxonomic descriptions of the soils available in the STATSGO database for the Red Fleet Reservoir catchment area are listed in Table 9.



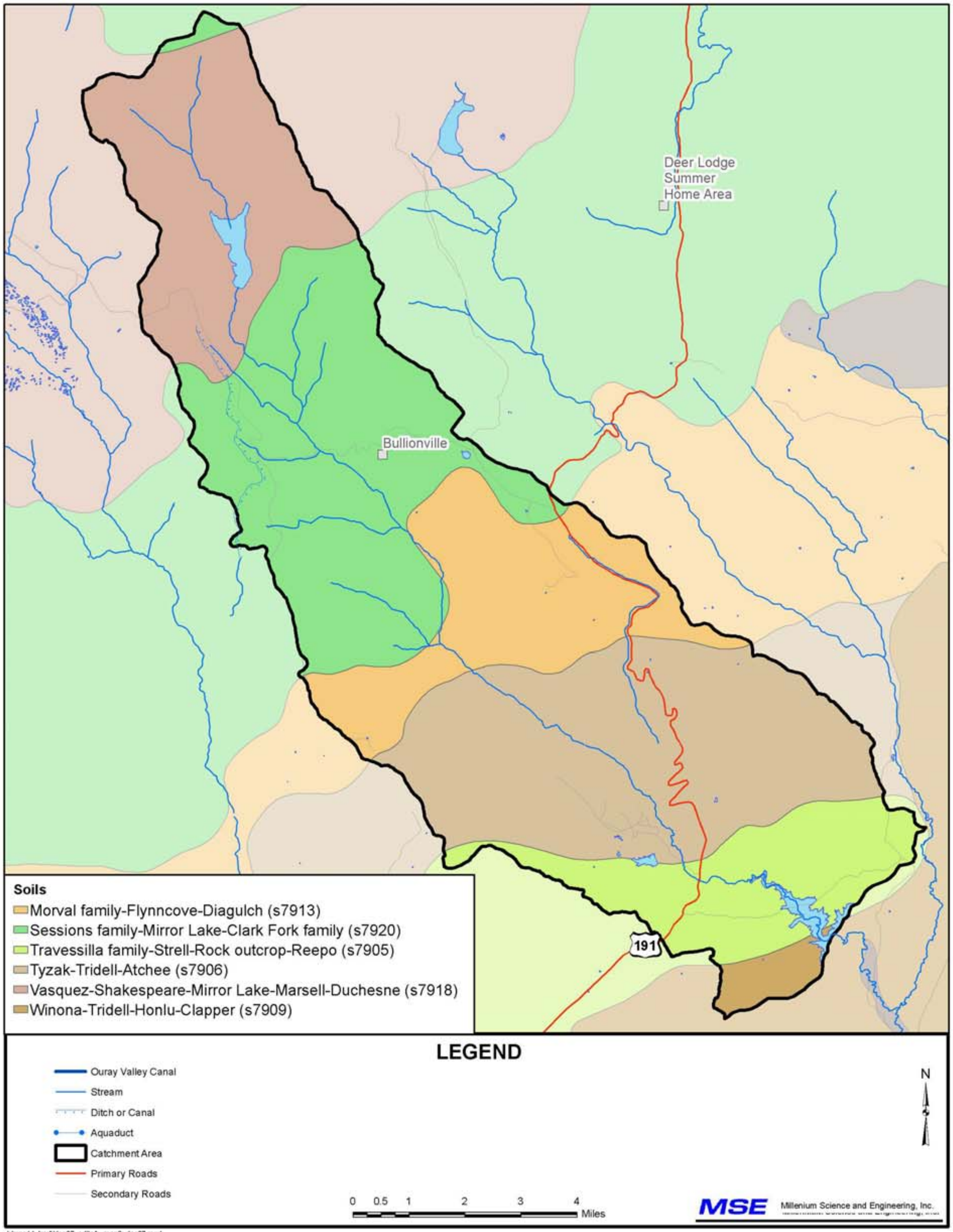
Map 15 Red Fleet Reservoir – General Topography



Map 16 Red Fleet Reservoir – Geology



Map 17 Red Fleet Reservoir – Soils (SURGO)



Map 18 Red Fleet Reservoir – Soils (STATSGO)

Table 9
STATSGO Soil Taxonomic Classifications in the Red Fleet Reservoir Catchment Area

SOIL NAME	TAXONOMIC CLASSIFICATION
Atchee	LITHIC USTIC TORRIORTHENTS, LOAMY-SKELETAL, MIXED (CALCAREOUS), MESIC
Clapper	USTOLLIC CALCIORTHIDS, LOAMY-SKELETAL, MIXED, MESIC
Clark Fork family	TYPIC USTORTHENTS, SANDY-SKELETAL, MIXED, FRIGID
Diagulch	ARIDIC HAPLOBOROLLS, FINE-LOAMY, MIXED
Duchesne	TYPIC CRYOBORALFS, LOAMY-SKELETAL, MIXED
Flynncove	ARIDIC ARGIBOROLLS, LOAMY-SKELETAL, MIXED
Honlu	USTOLLIC CALCIORTHIDS, FINE-LOAMY, MIXED, MESIC
Marsell	DYSTRIC CRYOCHREPTS, LOAMY-SKELETAL, MIXED
Mirror Lake	TYPIC CRYORTHENTS, SANDY-SKELETAL, MIXED
Morval family	ARIDIC ARGIBOROLLS, FINE-LOAMY, MIXED
Reepo	USTIC TORRIPSAMMENTS, MIXED, MESIC
Sessions family	ARGIC CRYOBOROLLS, FINE, MONTMORILLONITIC
Shakespeare	AQUIC CRYOBORALFS, LOAMY-SKELETAL, MIXED
Strell	LITHIC USTIPSAMMENTS, MIXED, FRIGID
Travessilla family	LITHIC USTIC TORRIORTHENTS, LOAMY, MIXED (CALCAREOUS), MESIC
Tridell	ARIDIC CALCIBOROLLS, LOAMY-SKELETAL, MIXED
Tyzak	LITHIC CALCIBOROLLS, LOAMY-SKELETAL, MIXED
Vasquez	HUMIC PERGELIC CRYAQUEPTS, COARSE-LOAMY, MIXED, ACID
Winona	LITHIC USTOLLIC CALCIORTHIDS, LOAMY-SKELETAL, CARBONATIC, MESIC

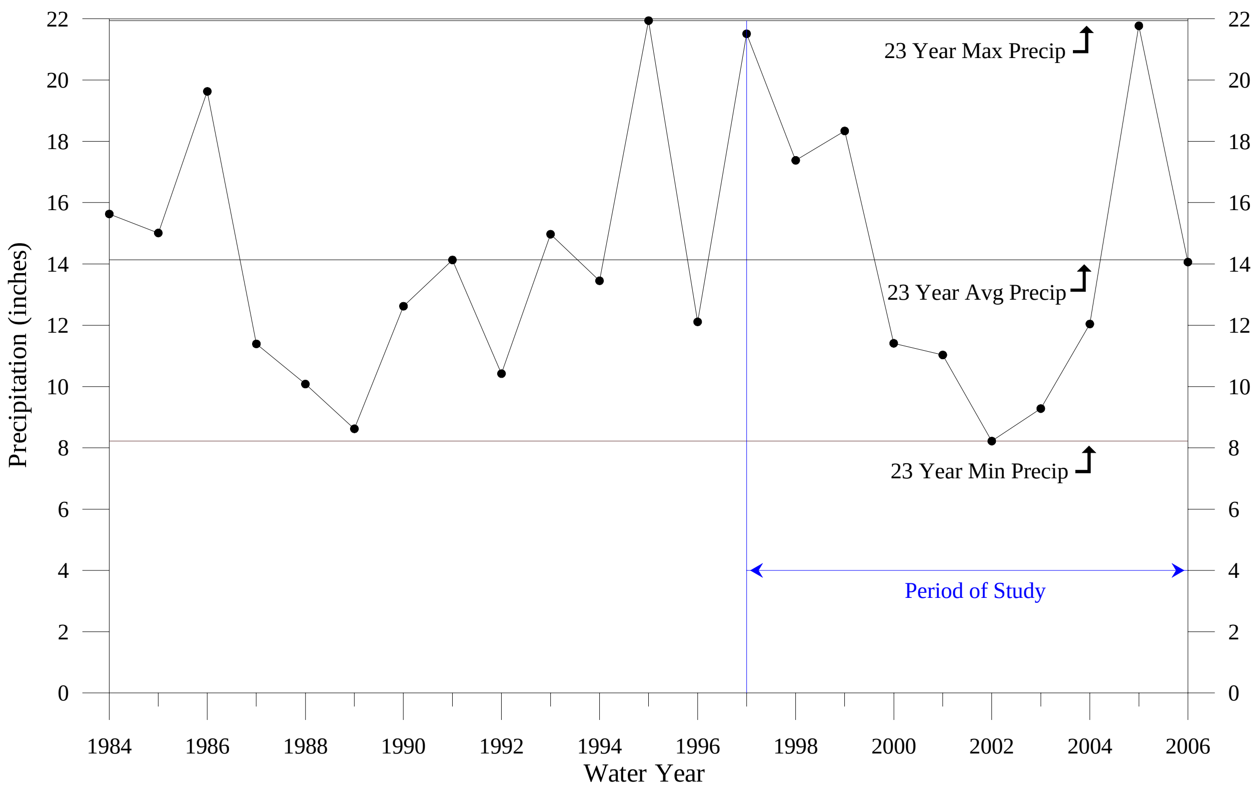
2.2.4 Climate

For this water quality study, there are two climate stations located near Red Fleet Reservoir and Ashley Creek. These climate stations are located at Maeser and the Vernal Airport, Utah. Among these stations the most complete climate record is from the station located in Maeser, Utah. This climate station is identified as "Maeser 9 NW, Utah (426268)" and is located approximately eleven miles west of Red Fleet Reservoir.

The period of record for the Maeser 9 NW station is from 1983 to 2006. A climate summary for the Maeser 9 NW station is included in **Error! Reference source not found.**. At the Maeser 9 NW climate station, the 23 year average annual precipitation was 14.34 inches with average annual snowfall of 60.5 inches, with average maximum temperature of 58.5° F and an average minimum temperature of 32.4° F.

Precipitation data from the Maeser 9 NW climate station were totaled for the water years (October 1 through September 30) 1983 to 2006. For these water years the maximum precipitation was 21.9 inches, the minimum precipitation was 8.22 inches and the average precipitation was 14.1 inches (see Figure 4).

Figure 4
MAESER 9 NW, Utah (426268) Climate Station
1983 - 2006 Water Year - Total Precipitation



As shown in Figure 4, the last ten water years at the Maeser 9 NW climate station include two approximate maximum precipitation events (21.5 inches in 1997 and 21.8 inches in 2005) and one minimum precipitation event (8.2 inches in 2002). The precipitation record for the last 10 years includes two wet years and one dry year. Therefore, to address the seasonality of data through wet and dry years, the appropriate period of study for the Red Fleet Reservoir water quality study and TMDL is October 1, 1996 to September 30, 2006 (the 1997 water year is from October 1, 1996 through September 30, 1997). Data evaluation for the Red Fleet Reservoir water quality study and TMDL will be limited to data (e.g., water quality and flow) available since October 1, 1996.

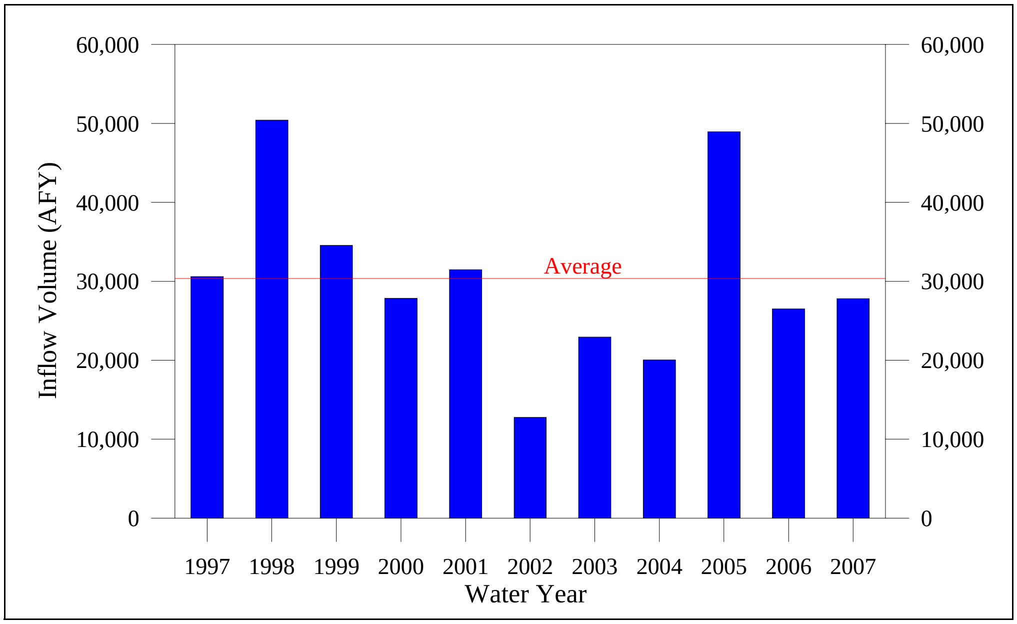
2.2.5 Watershed Hydrology

Water flows into Red Fleet Reservoir from Big Brush Creek. There is one stream gage station located on Big Brush Creek - a USGS gaging station located approximately 950 ft below State Highway 44 (see Map 12). Big Brush Creek flows from Oak Park Reservoir through Big Brush Gorge, where water often seeps into the stream channel and reappears as multiple springs lower in the watershed (John Hunting - UWCD, pers. comm. 2007). Fifth order watersheds that contribute water to Big Brush Creek include: Cottonwood Wash, Cottonwood Canyon, Big Brush Gorge, and Upper Big Brush Creek.

As discussed in Section 2.2.1, the areas that contribute flows to Red Fleet Reservoir were estimated by development of a catchment area. The catchment area was compiled from the 5th order hydrologic units (captured from the hydrologic dataset downloaded from the State Geographic Information Database [SGID], obtained from the Utah Automated Geographic Reference Center [AGRC]) and includes only those areas that contribute flow to Red Fleet Reservoir. The resulting catchment area for Red Fleet Reservoir is shown on Map 12. The catchment area encompasses 59,827 acres.

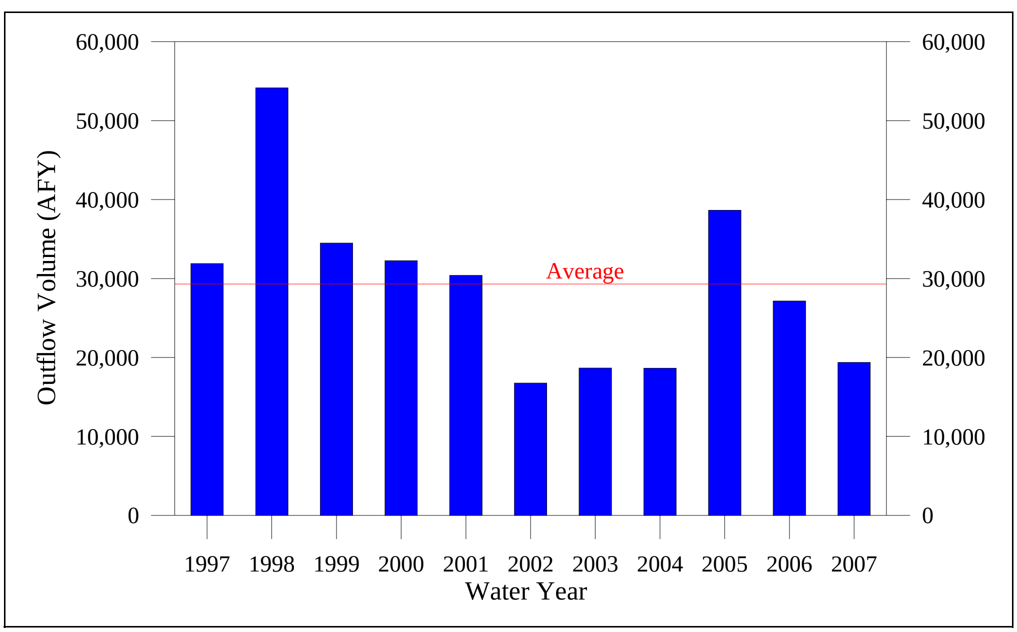
Flow data at the USGS gage on Big Brush Creek is collected and managed by the USGS and available on-line at: http://ut.water.usgs.gov/Basins/GreenRiverBasin/09261700.html. Flow records from this gage for the period of study are provided in **Error! Reference source not found.**. Variation in the inflow for water years 1997 to 2007 are shown in Figure 5.

Figure 5
Annual Variation in Red Fleet Reservoir Inflow



Reservoir water elevation and outflow data are collected by the Uintah Water Conservancy District and digitally recorded by the U. S. Bureau of Reclamation (BOR). The reservoir water elevation and outflow data in **Error! Reference source not found.** were provided by DWQ. Variation in the outflow for water years 1997 to 2007 are shown in Figure 6.

Figure 6
Annual Variation in Red Fleet Reservoir Outflow



A water budget was calculated for Red Fleet Reservoir, based upon inflow and outflow measurements provided by UWCD, the Bureau of Reclamation and DWQ. The water budget compares sources of water to ways in which water is lost from the reservoir. The budget can be summarized as:

Sources		Losses
Tributary + Precipitation	=	Reservoir Releases - Evaporation +/- Unmeasured Sources

The primary sources of water to Red Fleet Reservoir are inflows from Big Brush Creek and precipitation. Primary losses are outflow via releases and evaporation.

The water budget was determined by calculating measured values for each component for the water years 1997 through 2007. The average inflow was 41.9 cfs (30,354 AFY) for this period. A precipitation of 14.3 in/yr was specified, based the upon climate station identified as "Maeser 9 NW, Utah (426268)" located approximately 11 eleven miles west of Red Fleet Reservoir. This precipitation value corresponds to an annual water gain of 621 AFY, after multiplying precipitation rate (in/y) by the surface area of the reservoir (521 acres).

The average outflow for the period was 40.5 cfs (29,340 AFY). An evaporation of 35 inches per year was specified, based upon data from Vernal Airport, the nearest weather station with available data. This evaporation value corresponds to an annual water loss of 1,520 AFY, after multiplying evaporation rate (35 in/y) by the surface area of the reservoir. A summary of the water budget is shown below in Table 10. Unmeasured losses account for 0.4% of the overall water budget.

Table 10
Water Budget for Red Fleet Reservoir

Sources	Flow (AFY)
Big Brush Creek	30,354
Precipitation	621
Losses	
Outflow	-29,340
Evaporation	-1,520
Unmeasured Losses	
Groundwater/Ungaged Flow*	-116

*Calculated to provide water balance

2.2.6 Fisheries

Red Fleet Reservoir is managed as a put-and- take sport fishery by the Utah Division of Wildlife Resources. The reservoir is stocked with Fish Lake DeSmet (a fast growing strain) Rainbow Trout reared by the U.S. Fish and Wildlife Service (USFWS) Jones Hole National Fish Hatchery. The hatchery releases roughly 20,000 8-inch trout annually in the spring. Largemouth bass, bluegill and Green sunfish are well established and a small number of brown trout have entered the reservoir from Big Brush Creek. The Utah DWR considers the reservoir a productive trout fishery based on an assessment of survival and growth of stocklings, a favorable catch rate of 0.4 fish/hour, creel surveys and gill net surveys. In 2004, the catch rate was 0.42 fish net hour with a mean length of 308 mm, a mean weight of 412 g, a condition factor of 1.4 and a fat index of 1.1.

2.3 Steinaker Reservoir

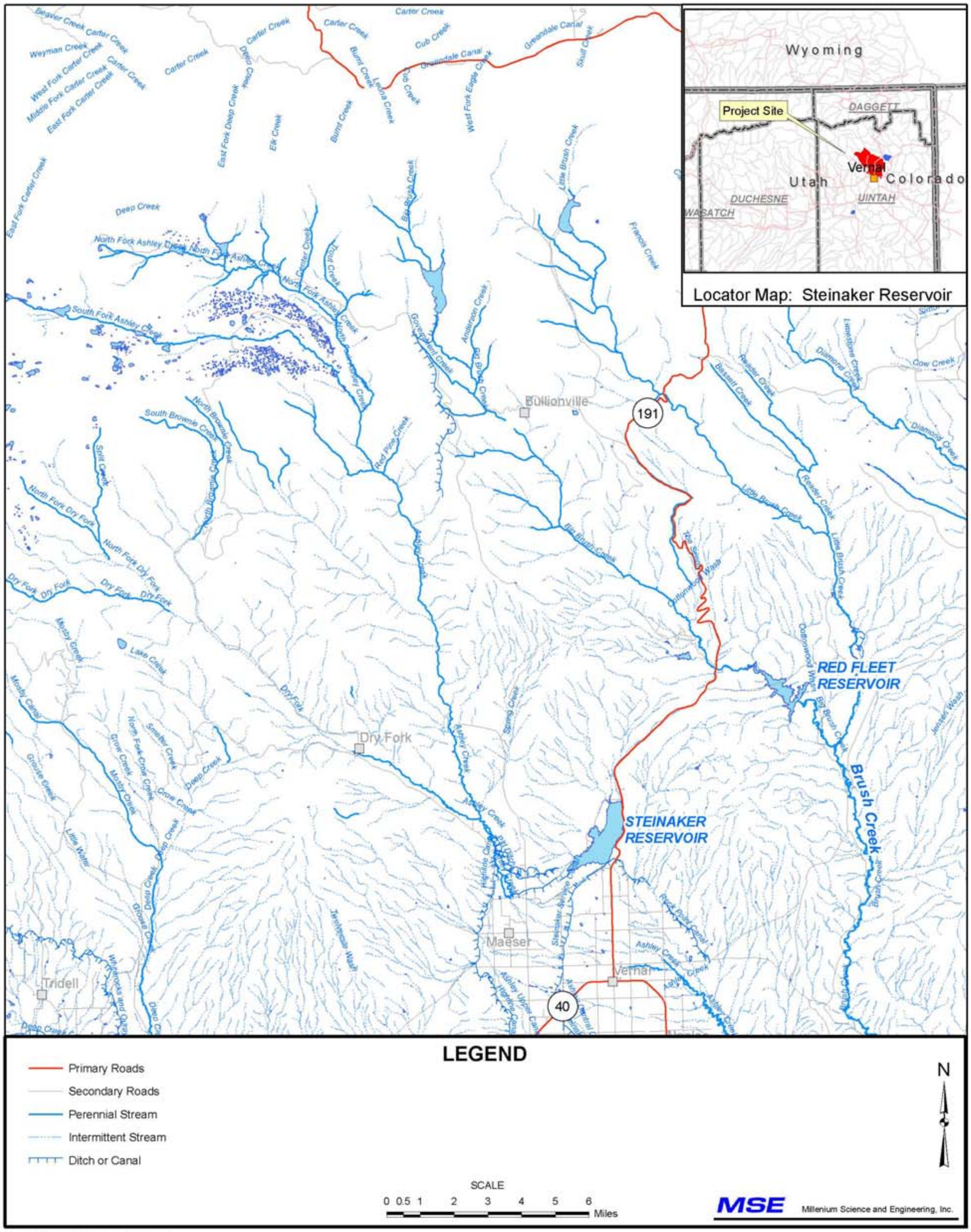
2.3.1 Location

Steinaker Reservoir is located in north-eastern Utah, 3.5 miles north of Vernal and lies within the Green River Basin of the Upper Colorado River Basin. The reservoir is in the Uinta Basin Watershed Assessment Unit (UT-L-14060002-004) and part of the Ashley-Brush Watershed identified with 4th order (8-digit) Hydrologic Unit Code (HUC) – 14060002. Within the Ashley-Brush Watershed, Steinaker Reservoir is situated in the Lower Ashley Creek watershed and Steinaker Reservoir sub-watershed. The location of Steinaker Reservoir is shown on Map 19.

The areas that contribute flows to Steinaker Reservoir were estimated by development of a catchment area. The methods used to develop the catchment area are described in Section 2.2.52.3.5.

Steinaker Reservoir resides within the Steinaker State Park boundaries. Highway 191 runs along the length of the park on the east side of the reservoir. State road UT-301 circles the reservoir on the northern and eastern sides of the reservoir allowing public access to recreational facilities.

An aerial photograph developed by the National Agriculture Imagery Program (NAIP) showing Steinaker Reservoir is provided on Map 20. The surrounding 5th and 6th order HUCs and the main tributaries to the reservoir – Ashley Creek and the Steinaker Feeder Canal - are shown on Map 21.



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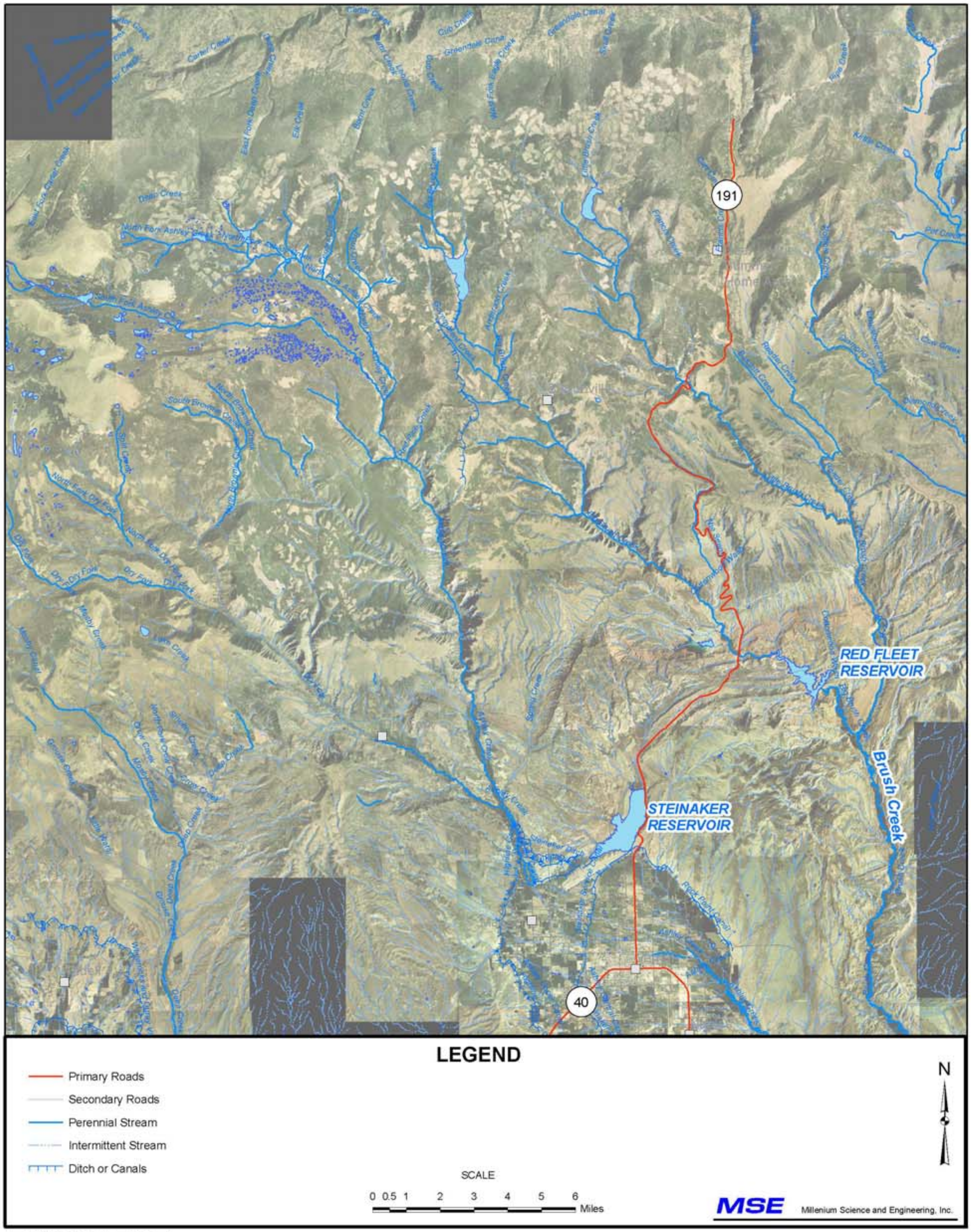
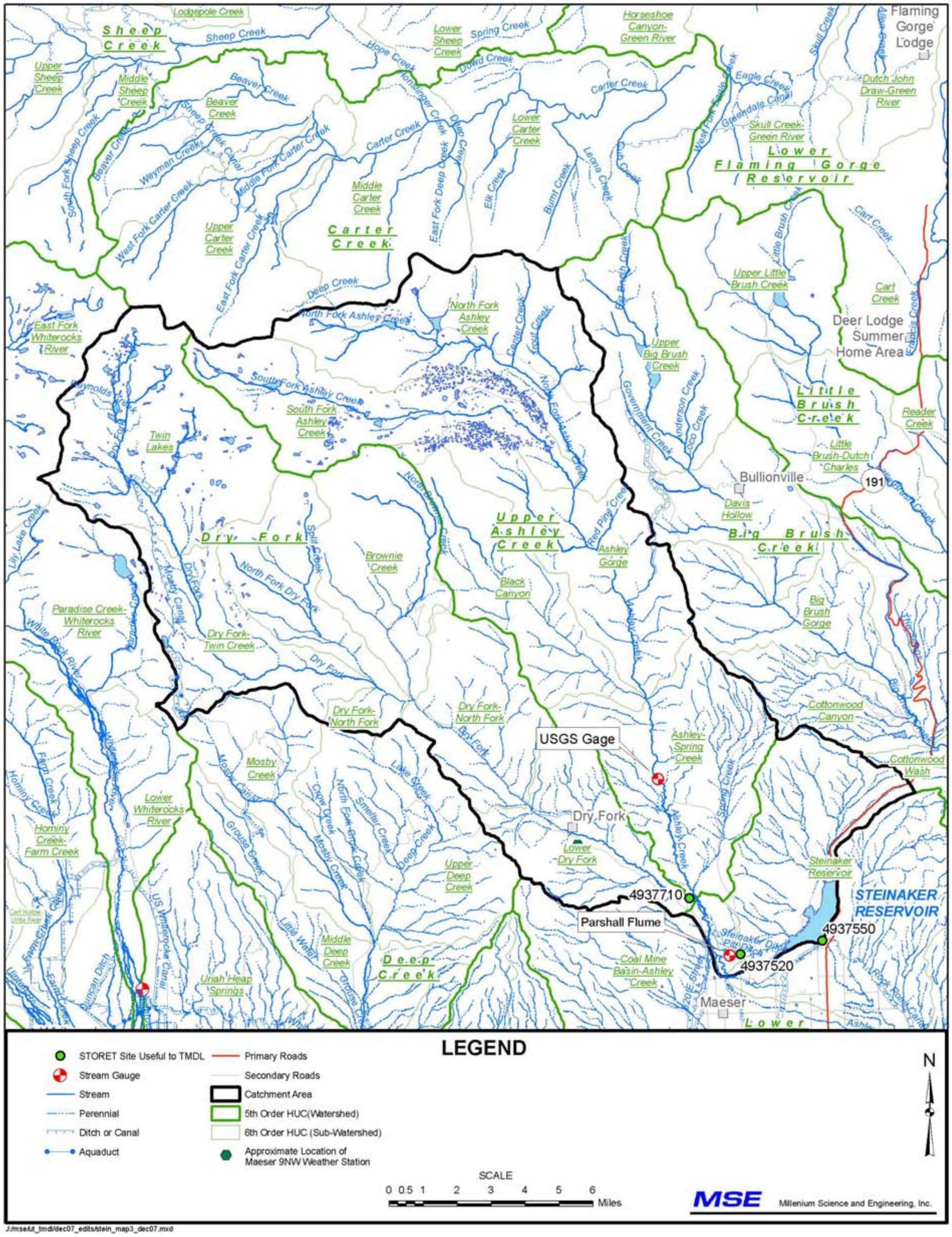
Map 19 Steinaker Reservoir - Location



Map 20 Steinaker Reservoir – NAIP Imagery



Map 21 Steinaker Reservoir – Hydrology

2.3.2 Land Ownership and Land Use/Cover

Map 22 and Map 23 show the land ownership and land use/cover in the Steinaker Reservoir catchment area, respectively.

The lands adjacent to Steinaker Reservoir are federally owned and lands along the Steinaker Feeder Canal are private. Lands along Ashley Creek from the Steinaker Feeder Canal diversion to the mouth of Dry Fork are privately owned. Above Dry Fork and approximately 5 miles to the Forest Service boundary, lands are mostly privately owned. The percentages of federal, private, and state owned lands in the catchment area are listed in Table 11.

Table 11
Land Ownership in the Steinaker Reservoir Catchment Area

Land Ownership	Acres	Percent of Catchment Area
Federal	150,068	90%
Private	12,098	7%
State	4,586	3%
Total	166,752	100%

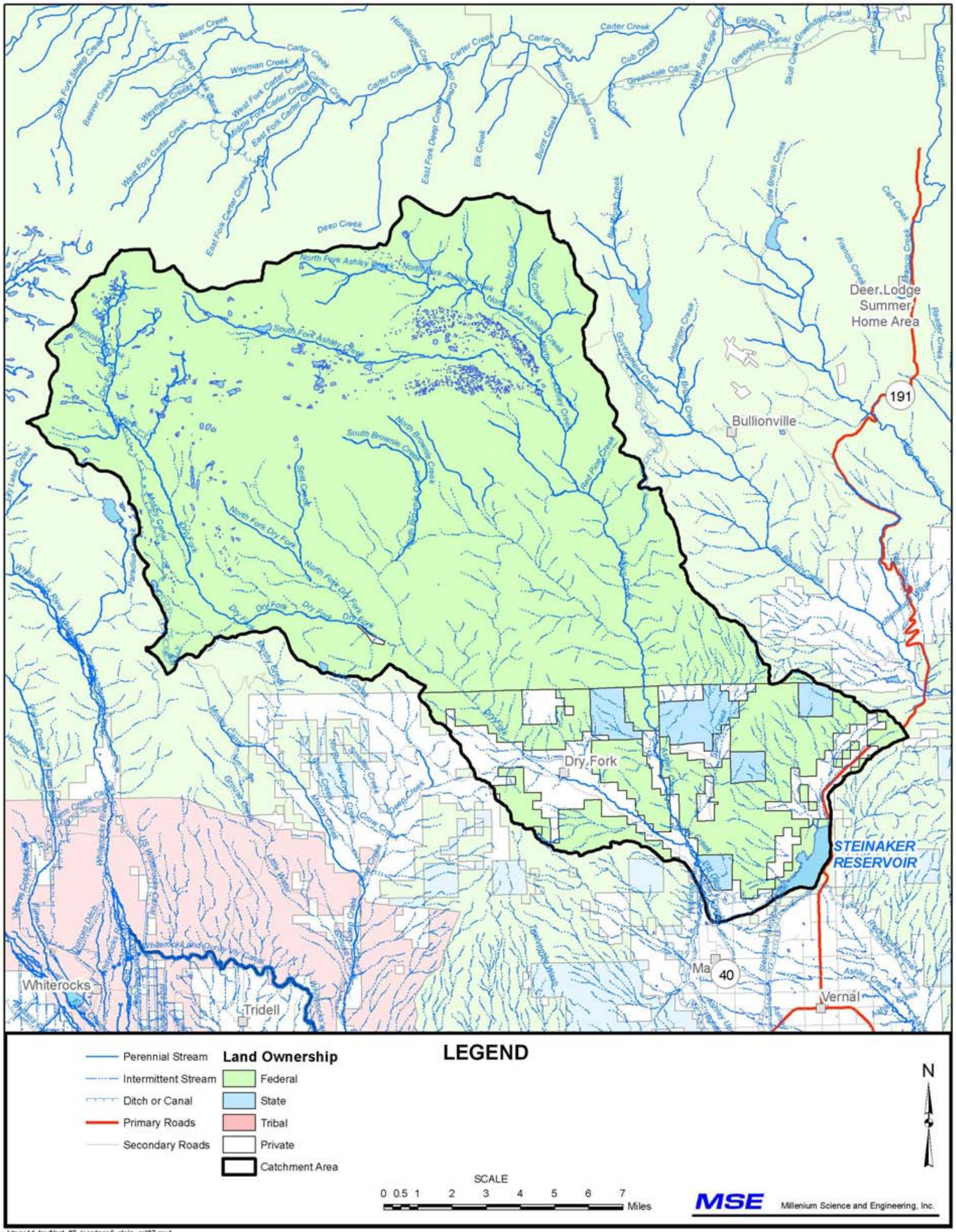
The lands adjacent to Steinaker Reservoir are mapped as shrubland. Lands along the Steinaker Feeder Canal are mapped as pasture/hay with shrublands. Lands along Ashley Creek from the Steinaker Feeder Canal diversion to the mouth of Dry Fork are mapped as pasture/hay with deciduous forest near Dry Fork. Above Dry Fork and approximately 5 miles to the Forest Service boundary, the land cover consists of evergreen and deciduous forest. Evergreen forest accounts for 45% of the land cover in the catchment area. Shrublands account for 38%, deciduous forest 9%, grasslands 4% of the land cover in the catchment area.

The Environmental Assessment conducted by the Bureau of Reclamation (2007) provides additional information on land cover in the watershed:

> "Much of the reservoir's perimeter consists of upland vegetation, predominately sagebrush, as well as rocky or bare ground. Other sections of the reservoir's shoreline consist of littoral cottonwood and willow habitats. This habitat varies from approximately 50 to several hundred feet in width and length and consists mostly of young willow, some Nebraska sedge and in places an overstory of

narrow leaf cottonwood. These habitats occur mainly along shallower areas where intermittent and perennial creek drainages convey fine textured sediment to the reservoir. These habitats require lake levels that closely approach or inundate (to a certain extent) these areas to ensure sufficient water.

Both nonnative and native species of vegetation are found within the project area in habitats around and above the reservoir. Upland habitat consists mainly of big sagebrush, and rabbit brush. Other species present include yellow sweet clover, houndstongue, broom snakeweed, golden currant, wild rose, basin wildrye, Rocky Mountain aster, Indian paintbrush, and curlycup gumweed. Crested wheatgrass has been seeded in previously disturbed areas. Canada thistle has invaded the area in small patches."



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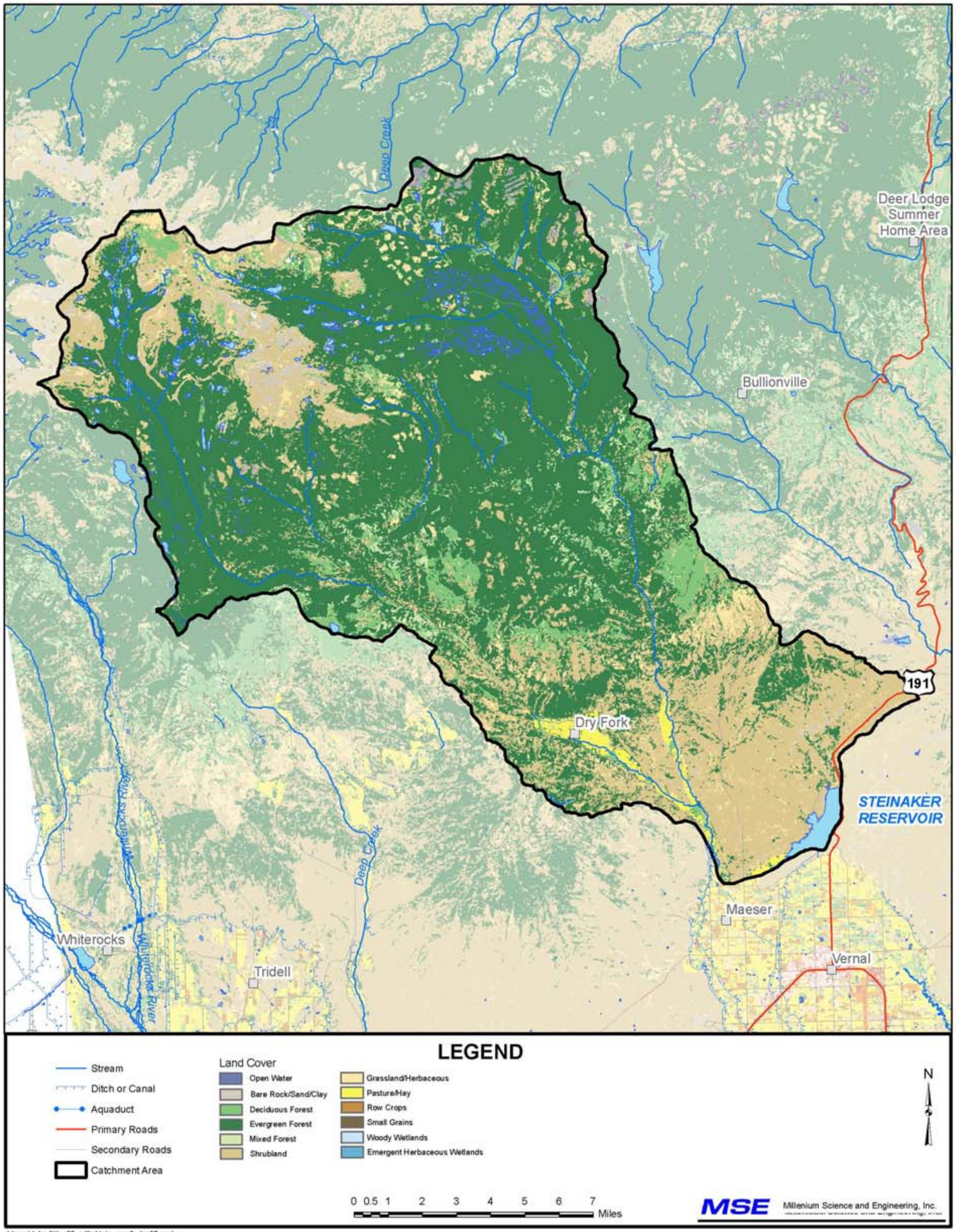
Map 22 Steinaker Reservoir – Land Ownership



Map 23 Steinaker Reservoir – Land Use

2.3.3 Geology and Soils

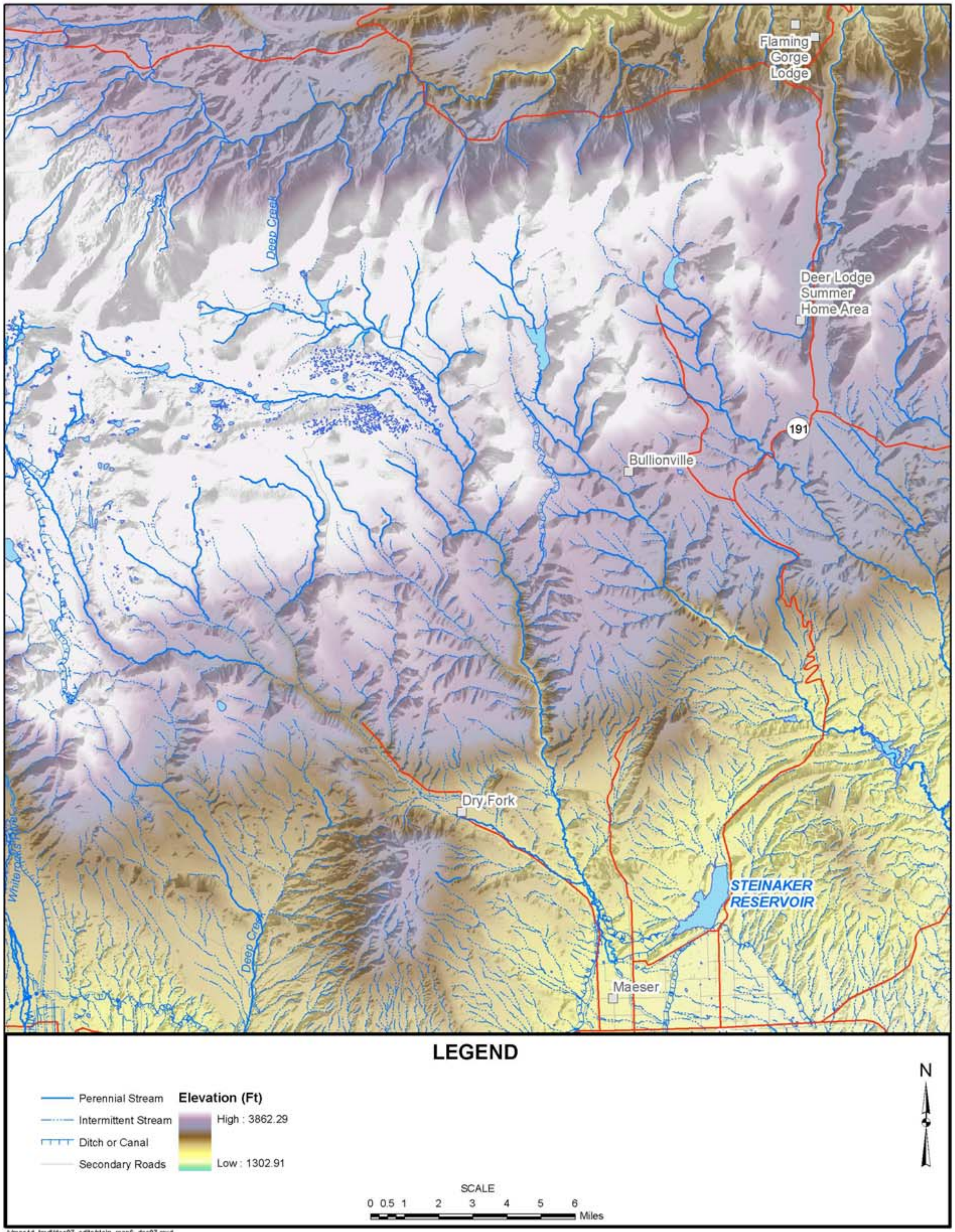
The reservoir is situated at 5,520 feet above sea level. The watershed is made up of high mountains, foothills, plateaus, badlands and valleys. The watershed high point, Marsh Peak, is 3,731 m (12,240 ft) above sea level, thereby developing a complex slope of 6.5% to the reservoir. The average stream gradient in the lower reaches of Ashley Creek is 2.3% (121 feet per mile), but is much steeper in the upper reaches of Ashley Creek and lower in the Steinaker Feeder Canal (DWR, 2005). The topography of Steinaker Reservoir watershed is shown on Map 24.

The geology adjacent to Steinaker Reservoir consists of marine deposits (Stump and Carmel Formations, and Mowry Shale), sandstones (Entrada, Frontier, and Dakota Sandstones); and mixed alluvium, colluvium, and eolian deposits. Along the channel of Ashley Creek the geology consists of flood-plain alluvium with Nugget Sandstone in the valley. Map 25 shows the geology within the Steinaker reservoir watershed.

At the foothills of the southern slope of the Uinta Mountains, approximately 3 miles north of Dry Fork, the geology consists of shales of the Chinle Formation; siltstone, shale, and sandstone of the Moenkopi Formation; marine mudstone, sandstone and limestone of the Dinwoody Formation. A large part of the south slope of the Uinta Mountains consists of the Park City and Phosphoria Formations composed of phosphate deposits. Sandstones and limestones of the Weber Sandstone and Morgan Formation make up the channel of Ashley Creek as it enters the high Uinta Mountains.

The total length of the Ashley Creek stream channel that passes through the Park City and Phosphoria formation is 19,501 feet. Of this total length, 150 feet (1%) come into direct contact with the formation (predominantly at the southern reach of the formation). Approximately 2,550 feet (13%) of stream channel is within 500 feet of the formation, with the remaining 16,801 feet (86%) outside the 500 foot proximity.

Available soils data in the Steinaker Reservoir catchment area were obtained from SURGO (Map 26) and STATSGO (Map 27). Exposed reservoir bottom (existing during seasonally low reservoir levels) consists of muddy and rocky substrates depending on the topography of the exposed shoreline. Large expanses of muddy exposed reservoir bottom typically occur where drainages deposit fine textured sediment into the reservoir (BOR, 2007). Taxonomic descriptions of the soils available in the STATSGO database for the Red Fleet Reservoir catchment area are listed in Table 12.



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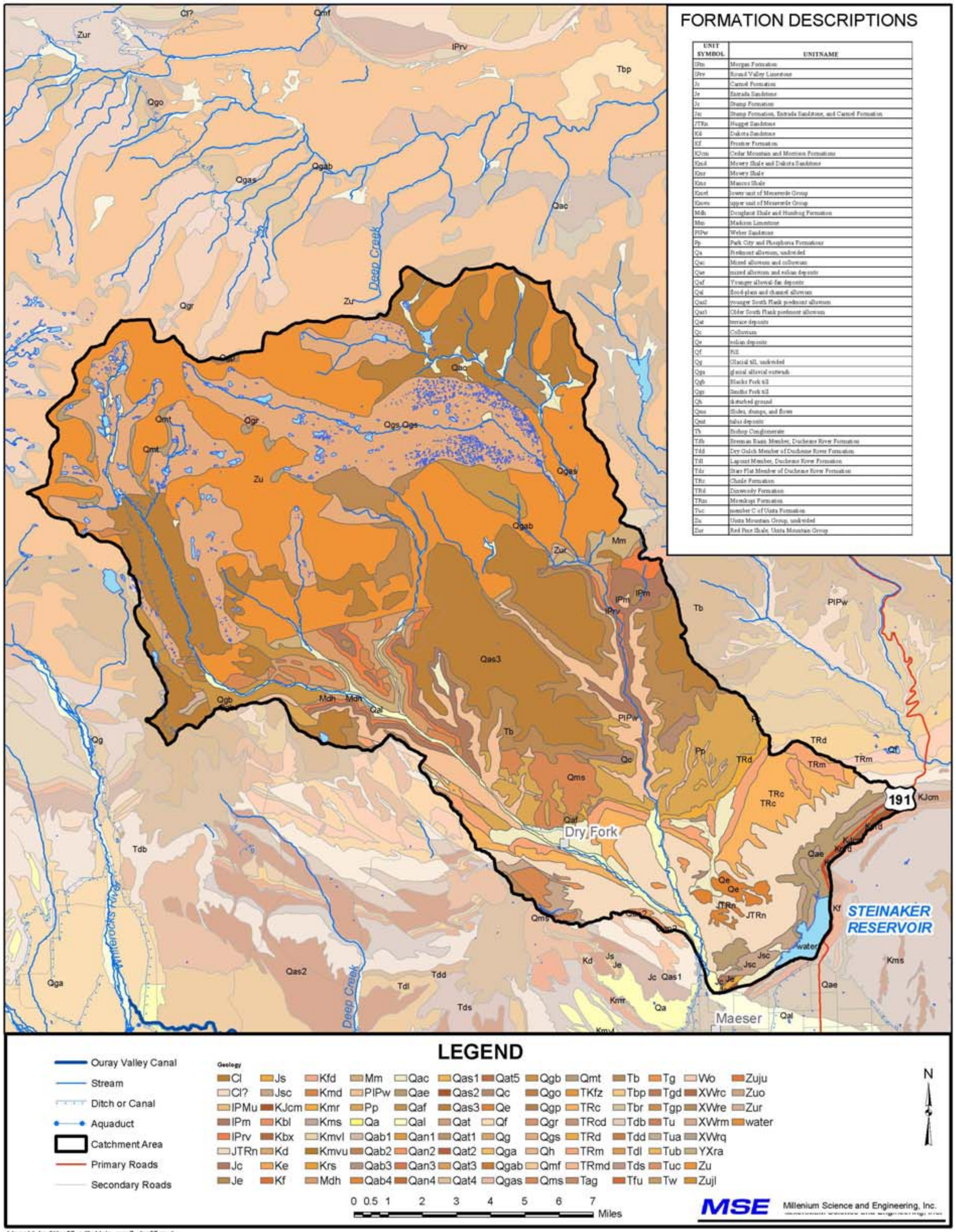
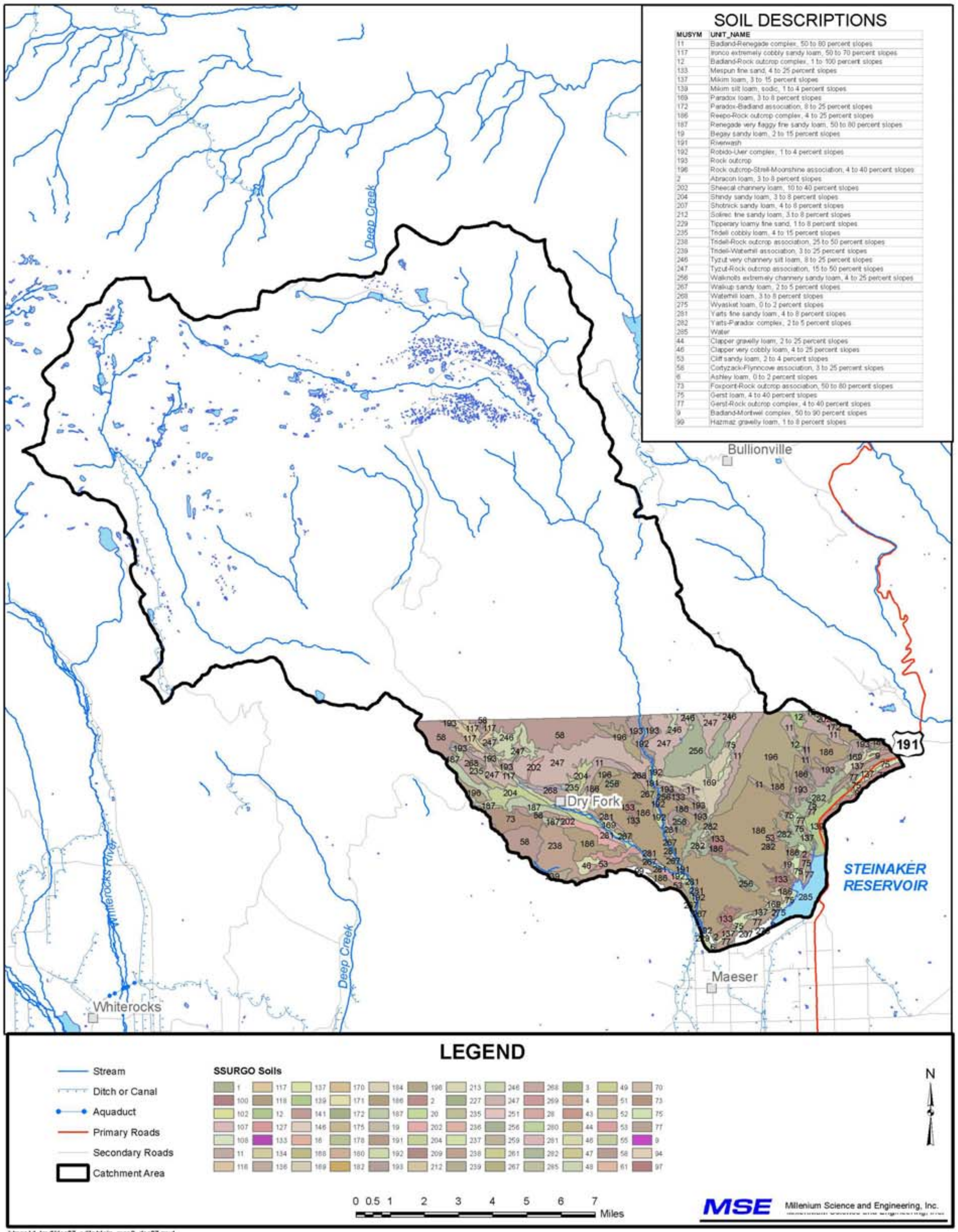
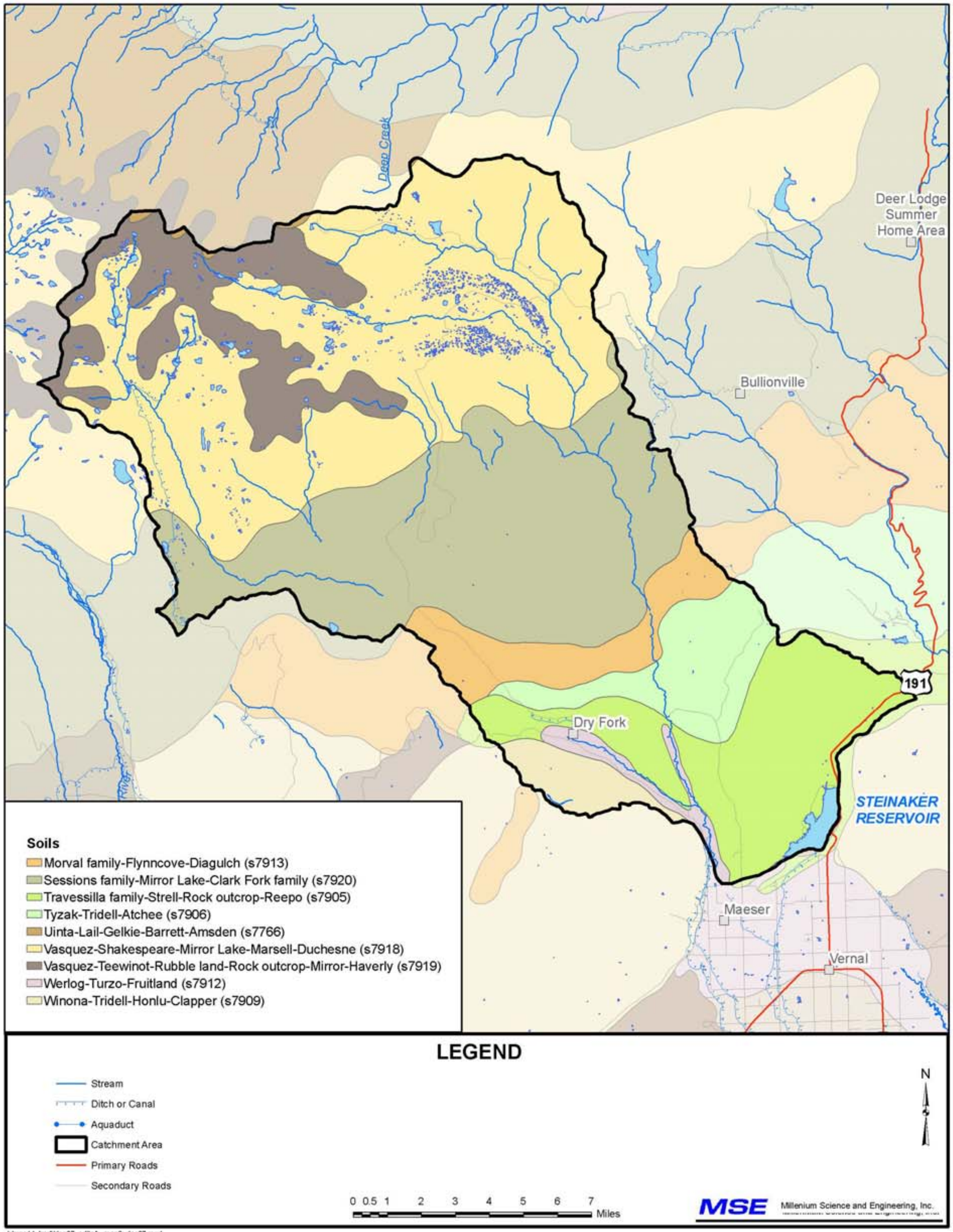
Map 24 Steinaker Reservoir – General Topography



Map 25 Steinaker Reservoir – Geology



Map 26 Steinaker Reservoir – Soils (SURGO)



Map 27 Steinaker Reservoir – Soils (STATSGO)

Table 12
STATSGO Soil Taxonomic Classifications in the Steinaker Reservoir Catchment Area

SOIL NAME	TAXONOMIC CLASSIFICATION
Amsden	ARGIC CRYOBOROLLS, FINE-LOAMY, MIXED
Atchee	LITHIC USTIC TORRIORTHENTS, LOAMY-SKELETAL, MIXED (CALCAREOUS), MESIC
Barrett	TYPIC CRYORTHENTS, LOAMY-SKELETAL, MIXED (CALCAREOUS), SHALLOW
Clapper	USTOLLIC CALCIORTHIDS, LOAMY-SKELETAL, MIXED, MESIC
Clark Fork family	TYPIC USTORTHENTS, SANDY-SKELETAL, MIXED, FRIGID
Diagulch	ARIDIC HAPLOBOROLLS, FINE-LOAMY, MIXED
Duchesne	TYPIC CRYOBORALFS, LOAMY-SKELETAL, MIXED
Flynncove	ARIDIC ARGIBOROLLS, LOAMY-SKELETAL, MIXED
Fruitland	TYPIC TORRIORTHENTS, COARSE-LOAMY, MIXED (CALCAREOUS), MESIC
Gelkie	ARGIC CRYOBOROLLS, FINE-LOAMY, MIXED
Haverly	PERGELIC CRYUMBREPTS, COARSE-LOAMY, MIXED
Honlu	USTOLLIC CALCIORTHIDS, FINE-LOAMY, MIXED, MESIC
Lail	TYPIC CRYOBORALFS, FINE, MONTMORILLONITIC
Marsell	DYSTRIC CRYOCHREPTS, LOAMY-SKELETAL, MIXED
Mirror	PERGELIC CRYUMBREPTS, LOAMY-SKELETAL, MIXED
Mirror Lake	TYPIC CRYORTHENTS, SANDY-SKELETAL, MIXED
Morval family	ARIDIC ARGIBOROLLS, FINE-LOAMY, MIXED
Reepo	USTIC TORRIPSAMMENTS, MIXED, MESIC
Sessions family	ARGIC CRYOBOROLLS, FINE, MONTMORILLONITIC
Shakespeare	AQUIC CRYOBORALFS, LOAMY-SKELETAL, MIXED
Strell	LITHIC USTIPSAMMENTS, MIXED, FRIGID
Teewinot	LITHIC CRYUMBREPTS, LOAMY-SKELETAL, MIXED
Travessilla family	LITHIC USTIC TORRIORTHENTS, LOAMY, MIXED (CALCAREOUS), MESIC
Tridell	ARIDIC CALCIBOROLLS, LOAMY-SKELETAL, MIXED
Turzo	TYPIC TORRIORTHENTS, FINE-LOAMY, MIXED (CALCAREOUS), MESIC
Tyzak	LITHIC CALCIBOROLLS, LOAMY-SKELETAL, MIXED
Uinta	TYPIC CRYOBORALFS, FINE-LOAMY, MIXED
Vasquez	HUMIC PERGELIC CRYAQUEPTS, COARSE-LOAMY, MIXED, ACID
Werlog	AQUIC USTIFLUVENTS, FINE-LOAMY, MIXED (CALCAREOUS), MESIC
Winona	LITHIC USTOLLIC CALCIORTHIDS, LOAMY-SKELETAL, CARBONATIC, MESIC

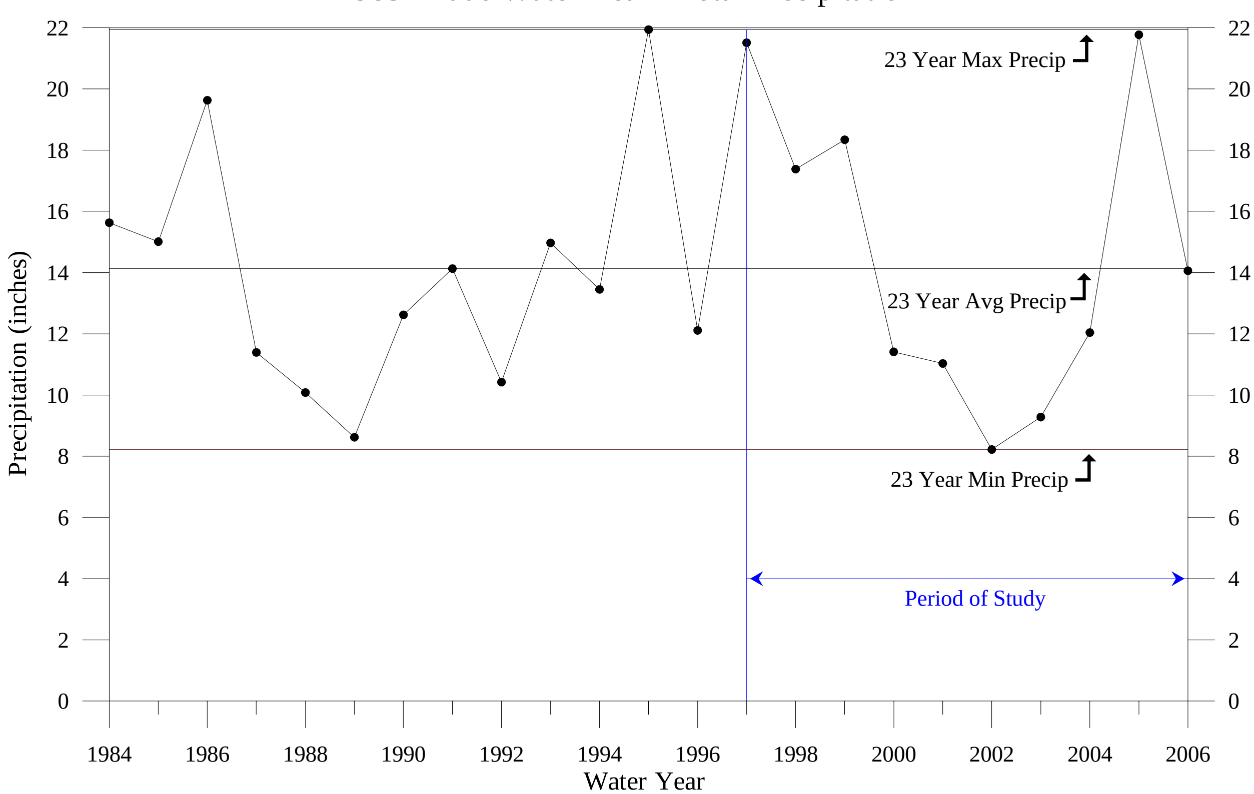
2.3.4 Climate

For this water quality study, there are two climate stations located near Steinaker Reservoir and Ashley Creek. These climate stations are located at Maeser and the Vernal Airport, Utah. Among these stations the most complete climate record is from the station located in Maeser, Utah. This climate station is identified as "Maeser 9 NW, Utah (426268)" and is located approximately 7 miles west of Steinaker Reservoir.

The period of record for the Maeser 9 NW station is from 1983 to 2006. A climate summary for the Maeser 9 NW station is included in **Error! Reference source not found.**. At the Maeser 9 NW climate station, the 23 year average annual precipitation was 14.34 inches with average annual snowfall of 60.5 inches, with average maximum temperature of 58.5° F and an average minimum temperature of 32.4° F.

Precipitation data from the Maeser 9 NW climate station were totaled for the water years (October 1 through September 30) 1983 to 2006. For these water years the maximum precipitation was 21.9 inches, the minimum precipitation was 8.22 inches and the average precipitation was 14.1 inches (see Figure 7).

Figure 7
MAESER 9 NW, Utah (426268) Climate Station
1983 - 2006 Water Year - Total Precipitation



As shown in Figure 1, the last ten water years at the Maeser 9 NW climate station include two approximate maximum precipitation events (21.5 inches in 1997 and 21.8 inches in 2005) and one minimum precipitation event (8.2 inches in 2002). The precipitation record for the last 10 years includes two wet years and one dry year. Therefore, to address the seasonality of data through wet and dry years, the appropriate period of study for the Steinaker Reservoir water quality study and TMDL is October 1, 1996 to September 30, 2006 (the 1997 water year is from October 1, 1996 through September 30, 1997). Data evaluation for the Steinaker Reservoir water quality study and TMDL will be limited to data (e.g., water quality and flow) available since October 1, 1996.

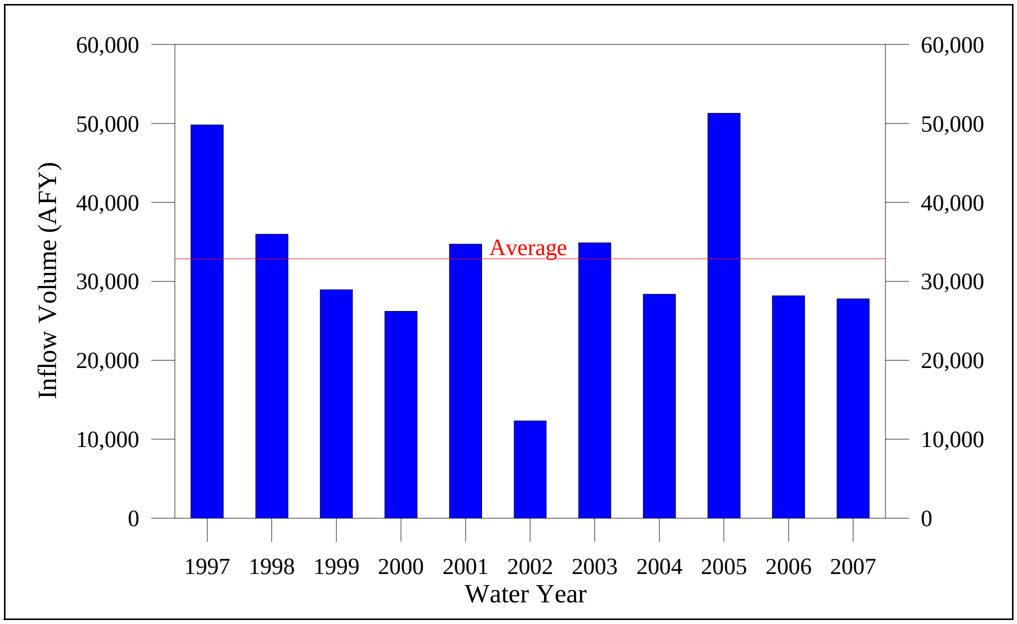
2.3.5 Watershed Hydrology

Water is diverted from Ashley Creek by the Fort Thornburgh Diversion Dam into the 2.8 mile Steinaker Feeder Canal that conveys water eastward into Steinaker Reservoir. There is a stream gage station at the head of the Steinaker Feeder Canal (a Parshall flume), and a USGS gaging station (926500) on Ashley Creek approximately seven miles north of the Fort Thornburgh Diversion Dam (see Map 21). Water is released from the reservoir into the Steinaker Service Canal.

As discussed in Section 2.3.1, the areas that contribute flows to Steinaker Reservoir were estimated by development of a catchment area. The catchment area was compiled from the 5th order hydrologic units (captured from the hydrologic dataset downloaded from the State Geographic Information Database [SGID], obtained from the Utah Automated Geographic Reference Center [AGRC]) and includes only those areas that contribute flow to Red Fleet Reservoir. The resulting catchment area for Steinaker Reservoir is shown on Map 21. The catchment area encompasses 166,752 acres.

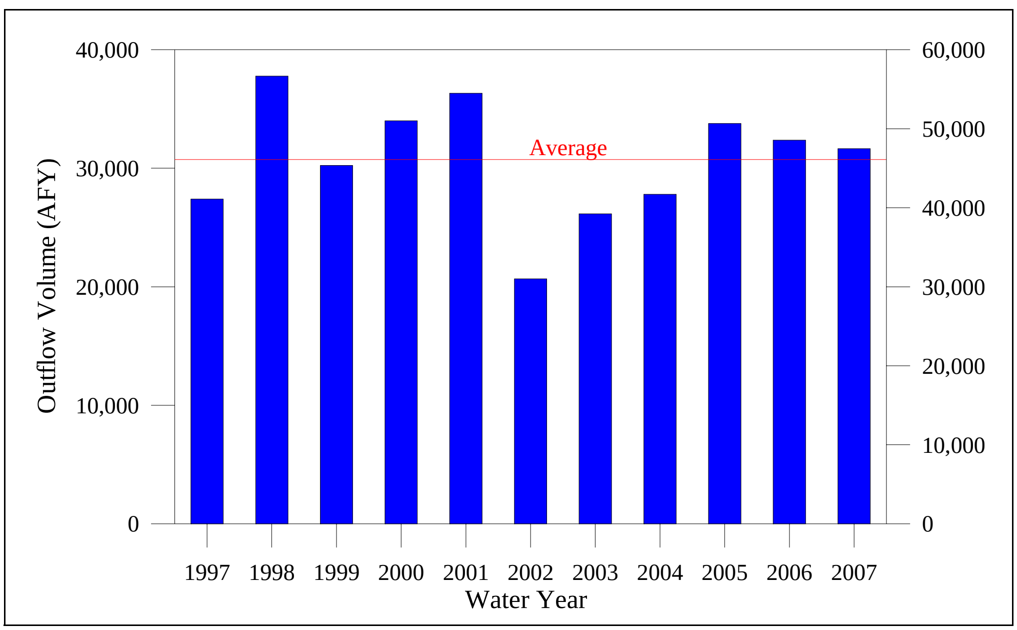
Flow data at the Parshall flume on the Steinaker Feeder Canal is collected by the Uinta Water Conservancy District and was provided to MSE during a site visit in April 2007. Flow data at the USGS gage on Ashley Creek is collected and managed by the USGS and available on-line at: http://ut.water.usgs.gov/Basins/GreenRiverBasin/09266500.html. Flow records from these two gages for the period of study are provided in **Error! Reference source not found.**. Variation in the inflow for water years 1997 to 2007 are shown in Figure 8.

Figure 8
Annual Variation in Steinaker Reservoir Inflow



Reservoir water elevation and outflow data are collected by the Uintah Water Conservancy District and digitally recorded by the U. S. Bureau of Reclamation (BOR). The reservoir water elevation and outflow data in **Error! Reference source not found.** were provided by DWQ. Variation in the outflow for water years 1997 to 2007 are shown in Figure 9.

Figure 9
Annual Variation in Steinaker Reservoir Outflow



A water budget was calculated for Steinaker Reservoir, based upon inflow and outflow measurements provided by UWCD, the Bureau of Reclamation, and DWQ. The water budget compares sources of water to ways in which water is lost from the reservoir. The budget can be summarized as:

Sources		Losses
Tributary + Precipitation	=	Reservoir Releases - Evaporation +/- Unmeasured Sources

The primary sources of water to Steinaker Reservoir are inflows from the Steinaker Feeder Canal and precipitation. Primary losses are outflow via releases and evaporation.

The water budget was determined by calculating measured values for each component for the calendar years 1997 through 2007. The average inflow was 45.4 cfs (32,857 AFY) for this period. A precipitation of 14.3 in/yr was specified, based the upon climate station identified as "Maeser 9 NW, Utah (426268)" located approximately seven miles west of Steinaker Reservoir. This precipitation value corresponds to an annual water gain of 988 AFY, after multiplying precipitation rate (in/y) by the surface area of the reservoir (829 acres).

The average outflow for the period was 42.4 cfs (30,742 AFY). An evaporation of 35 inches per year was specified, based upon data from Vernal Airport, the nearest weather station with available data. This evaporation value corresponds to an annual water loss of 2,418 AFY, after multiplying evaporation rate (35 in/y) by the surface area of the reservoir. A summary of the water budget is shown below in Table 13. Unmeasured losses account for 2% of the overall water budget.

Table 13
Water Budget for Steinaker Reservoir

Sources	Flow (AFY)
Steinaker Feeder Canal	32,857
Precipitation	988
Losses	
Outflow	-30,742
Evaporation	-2,418
Unmeasured Losses	
Groundwater/Ungaged Flow*	-685

*Calculated to provide water balance

2.3.6 Fisheries

Steinaker Reservoir is managed as a put-and-take sport fishery by the Utah Division of Wildlife Resources. The reservoir is stocked with Fish Lake DeSmet (a fast growing strain) Rainbow Trout (*Onchorycnchus mykiss*) reared by the U.S. Fish and Wildlife Service (USFWS) Jones Hole National Fish Hatchery. The hatchery releases approximately 30,000 8-inch trout annually in the spring. Other species found in the reservoir include largemouth bass (*Micropterus salmoides)*, bluegill (*Lepomis macrochirus)*, Green sunfish (*Lepomis cyanellus)* and a small number of brown trout (*Salmo trutta*) that have entered the reservoir from Ashley Creek. The Utah DWR considers the reservoir a productive trout fishery based on an assessment of survival and growth of stocklings, a favorable catch rate of 0.4 fish/hour, creel surveys, and gill net surveys (see Table 14). The reservoir was treated with rotenone in 1989 to remove illegally introduced species.

Table 14
Steinaker Reservoir Gill Net Surveys

YEAR	CATCH RATE (FISH/NET HOUR)	MEAN LENGTH (MM)	MEAN WEIGHT (G)	MEAN CONDITION	FAT INDEX
1988	0.03	178	55	0.98	0
1989	Treatment Year (October)				
1990	0.48	206	97	1.11	3.1
1991	1.3	290	246	1.01	3.3
1992	0.11	380	641	1.13	3.4
1993	0.58	355	355	1.08	3.5
1994	1.12	276	252	1.12	2.9
1995	0.4	379	679	1.25	3.9
1996	2.58	267	250	1.06	3.3
2004	0.46	378	629	1.16	2.0

3.0 RESERVOIR CHARACTERISTICS AND OPERATION

3.1 Brough Reservoir

3.1.1 History, Ownership, and Usage

Brough Reservoir was constructed in 1975 as an off-stream earth filled dam. The reservoir was constructed to store and deliver water for irrigation. Water is diverted into the reservoir from the Whiterocks River into the Ouray Valley canal.

The reservoir water is jointly owned and managed by the Ouray Park Irrigation Company and the Utah Division of Wildlife Resources for irrigation water and recreational angling, respectively (Judd, 1997). Recreational opportunities include fishing, boating, and hunting. There is no boat ramp at the reservoir, but small boats can be launched at stategic points. There are no camping areas or facilities located adjacent to the reservoir.

3.1.2 Physical dimensions

Brough Reservoir has a surface area of 128 acres, with a length of 3,400 feet and width of 2000 feet. Total capacity is 4,000 acre-feet, with 1,145 acre-feet at conservation pool. The maximum depth is 56 feet, with a mean depth of 31 feet. A pipeline was installed in 2003 to convey water from the reservoir to irrigated lands downstream.

3.1.3 Operations

Water delivered to irrigation lands south of the reservoir is managed by the Ouray Park Irrigation Company. The water right to fill the reservoir begins November 15th and continues until the reservoir is full. Irrigation deliveries begin April 1st and the reservoir is drawndown annually to the conservation pool of 1145 ac-ft which was procured by the Utah Division of Wildlife Resources for the fishery. The president of the Ouray Park Irrigation Company noted that irrigators receive half of their annual allotment of 3 acre-foot/share due to lack of supply.

3.2 Red Fleet Reservoir

3.2.1 History, Ownership, and Usage

Red Fleet Dam and Reservoir were constructed by the U.S. Bureau of Reclamation as part of the Jensen Unit of the Central Utah Project. Construction began in 1977 and was completed in 1980. Once completed, the operation and maintenance were turned over to the Uintah Water Conservancy District (UWCD) on May 1, 1985. Municipal water from the reservoir is sent to the Ashley Valley Water Treatment Plant via the Tyzack pumping plant through an aqueduct 11.7 miles long. Currently 2000 ac-ft per year out of the allotted 18,000 ac-ft per year are used for municipal and industrial water (John Hunting – UWCD, pers. comm. 2007). The Jensen Unit provides 4,600 acre-feet for irrigation lands in Ashley Valley and the area extending east of the valley to the Green River. (http://www.usbr.gov/uc/provo/aboutus/projects.html).

Recreational activities at Red Fleet State Park include: boating, fishing, water sports, hiking, picnicking and camping. There are 38 campsites, a swimming beach, day use picnic area, a concrete boat ramp, modern rest rooms, sewage disposal, and a fish cleaning station. The campground is open from April 15th through October 15th. Other Recreational Facilities include a Dinosaur Trackway Trail-1.5 miles each way with over 200 dinosaur tracks are visible most of the year. The north side of reservoir has a day use fishing area and small beach. No overnight camping is allowed in this area. In 2007, 37,826 people visited the park (Mike Murray, Park Manager, pers. comm. 2007).

3.2.2 Physical Dimensions

Red Fleet Reservoir has a total capacity of 26,170 acre-feet, of which 24,000 acre-feet is active storage (John Hunting - UWCD, pers. comm. 2007). A conservation pool of 4000 ac-ft is reserved for flood control and 300 ac-ft of water is inactive. The maximum depth is 145 feet, with a mean depth of 50 feet. The reservoir has a surface area of 521 acres, with a length of 1.7 miles and width of 0.6 miles. The normal water surface elevation is 5,608 feet (BOR, at: http://www.usbr.gov/dataweb/html/jensen.html).

3.2.3 Operations

Water delivered to irrigation lands is managed by the UWCD. The water right to fill the reservoir begins November 1st and continues until the reservoir is full. Irrigation deliveries begin April 1st until October 1st.

3.3 Steinaker Reservoir

3.3.1 History, Ownership, and Usage

Steinaker Reservoir was constructed by the U.S. Bureau of Reclamation and the Central Utah Water Conservancy District (CUWCD) as part of the Vernal Unit of the Central Utah Project (CUP). Projects completed as part of the Vernal Unit include Steinaker Dam and Reservoir, Forth Thornburgh Diversion Dam, Steinaker Service Canal, and the Steinaker Feeder Canal. Surplus flows of Ashley Creek are diverted through the Fort Thornburgh Diversion Dam and conveyed through the Steinaker Feeder Canal to the off stream Steinaker Reservoir. Water stored in the reservoir is released into the Steinaker Service Canal and delivered to irrigation canals and ditches. A supplemental water supply of 17,900 ac-ft is provided to about 14,781 acres. This water partially replaces Ashley Creek water, including releases from privately constructed upstream reservoirs. Some of the replaced water is used on lands upstream of the Steinaker Service Canal and some is diverted from Ashley Springs on Ashley Creek into the municipal pipelines through which about 1,600 acre-feet of water is delivered annually to the communities of Vernal, Naples, and Maeser. Reservoir water is released to Steinaker Service Canal and conveyed south 12 miles to canals and ditches.

Recreational activities at Steinaker State Park include: boating, fishing, water sports, hiking, picnicking and camping. There are 31 campsites, two swimming beaches, day use picnic area with two pavilions (limit 50 people), a concrete boat ramp, modern rest rooms, sewage disposal, and a fish cleaning station. The campground is open from April 15th through October 15th. Other Recreational Facilities include the Eagle Ridge Hiking Trail, a 1 mile loop nature trail of which ½ mile is elevated to be above high water in the northeast corner of the reservoir. In 2007, 55,666 people visited the park (Mike Murray, Park Manager, pers. comm. 2007).

3.3.2 Physical Dimensions

Steinaker Reservoir has a total capacity of 35,380 acre-feet, of which 33,280 acre-feet is active storage (John Hunting – UWCD, pers. comm. 2007). A dead pool of 3,718 ac-ft and an inactive pool of 1,782 ac-ft remains in the reservoir annually. The maximum depth is 130 feet, with a mean depth of 45.9 feet. The reservoir has a surface area of 829 acres, with a length of 2.61 miles and width of 0.56 miles. The normal water surface elevation is 5,178 feet (BOR, 2007).

3.3.3 Operations

Water delivered to irrigation lands is managed by the UWCD. The water right to fill the reservoir begins November 1st and continues until the reservoir is full. Irrigation deliveries begin April 1st until October 1st.

4.0 IMPAIRMENT ANALYSIS/EVALUATION

The data evaluated in this TMDL study were obtained from the Utah Division of Water Quality, the Uintah Water Conservancy District, the Ouray Park Irrigation Company, Utah Geological Survey, Western Regional Climate Center, Utah's Automated Geographic Reference Center (AGRC), Utah Division of Wildlife Resources, Utah Division of Water Rights, and the U.S. Bureau of Reclamation (BOR).

4.1 Brough Reservoir

4.1.1 Stations and Data

DWQ identified five STORET stations near Brough Reservoir. These stations and the years of available data for the period of study are listed in Table 15.

Table 15
STORET Stations Containing Water Quality Data for the Period of Study

STORET	Type	Description	Sample Years
5932410	River/Stream	BROUGH RESERVOIR SPILLWAY	1996 2002
5932420	River/Stream	CANAL BELOW BROUGH RES	1981
5932430	Lake	BROUGH RESERVOIR ABOVE DAM 01	1998 2000 2002 2003 2004 2006
5932440	Lake	BROUGH RESERVOIR MIDLAKE 02	1998 2000 2002 2003 2004 2006
5932450	River/Stream	CANAL ABOVE BROUGH RESERVOIR	1998 2000 2002 2003 2004 2005 2006

Three of the STORET stations listed in Table 15 have been sampled with sufficient frequency for the Brough Reservoir TMDL water quality study. These three STORET stations include: 5932430 (BROUGH RES AB DAM 01), 5932440 (BROUGH RES MIDLAKE 02), and 5932450 (CANAL AB BROUGH RESERVOIR). Water quality data from these stations were provided by DWQ.

The raw data and statistical summaries of available data for the period of record collected at the three STORET stations described above are provided in **Error! Reference source not found.**. For each station, the data was tabulated from the raw output and followed by descriptive statistics. The statistics list the number, minimum, maximum, mean, standard deviation, and the mean plus two standard deviations (for outlier analysis). Statistical summaries are included for all data, and data categorized by location in the water column where available. It is important to note that although percent exceedence is displayed in the table, it is not intended to be used in comparison to water quality criteria or 303(d) listing criteria.

Laboratory detection limits for each parameter were provided by DWQ. Where results were below the laboratory detection limit, one-half the detection limit was entered.

Outlier Analysis and Treatment of Results Below Laboratory Detection Limits

Results that fall outside the control limits of plus two standard deviations from the mean were judged to be suspected outliers and removed from further statistical analysis.

For reservoir sampling, DWQ collects depth profile data using a data sonde that records temperature, pH, specific conductivity, and dissolved oxygen at approximately one-meter intervals throughout the water column. Combined with depth profile sampling, grab samples are collected at the surface, one meter above the thermocline, one meter below the thermocline, and one meter from the bottom of the reservoir.

Parameters of interest to this TMDL water quality study and the number of reservoir samples collected during the period of study are list in Table 16.

Table 16
Parameters and Number of Results for Brough Reservoir STORET Stations for the Period of Study

Parameter	5932430 Brough Res Above Dam	5932440 Brough Res Mid Lake
Datalogger Profiles	Year – No. of Profiles: 2000 - 1 2002 - 2 2003 - 4 2004 - 2 2006 - 4	Year – No. of Profiles: 2002 - 2 2003 - 4 2004 - 2 2006 - 4
Number of Results (excluding outliers):		
Depth	197	122
Water Temperature	196	122
Dissolved Oxygen	194	122
Dissolved Oxygen Saturation	188	116
Total Phosphorus	40	23
Chlorophyll-a	15	15
Depth Secchi Disk	15	13
Nitrogen as Nitrate + Nitrite	48	22
Nitrogen as Ammonia	46	22

Additional data are available for the CANAL AB BROUGH RESERVOIR, STORET 5932450. For the period of study, data from this station are available in 1998, 2000, 2002, 2003, 2004, 2005, and 2006. Parameters of interest to this TMDL water quality study and the number of tributary samples collected during the period of study are listed in Table 17.

Table 17
Parameters and Number of Results for Brough Reservoir Tributary STORET Stations for the Period of Study

Parameter	5932450 Canal Abv Res
Number of Results (excluding outliers):	
Water Temperature	30
Dissolved Oxygen	28
Total Phosphorus	26
Dissolved Phosphorus	28
Nitrogen as Nitrate + Nitrite	28
Nitrogen as Ammonia	26
Total Suspended Solids	27
Turbidity	14

4.1.2 Summary of Impairment

STORET Station 5932430- Brough Reservoir Above Dam

STORET data for station 5932430 (Brough Reservoir Above Dam), includes data from 13 depth profiles in addition to other chemistry results for a total of 17 sampling events over the study period. The parameters of interest and associated statistics for evaluation of the water quality of Brough Reservoir as related to the impaired designated beneficial use (cold water fishery), due to low dissolved oxygen are listed in **Error! Reference source not found.** and summarized in Table 18.

Table 18
STORET Summary for Brough Reservoir Above Dam (5932430)

				Dissolved Oxygen				Total Phosphorus		
Date	**Depth (m)**	**n**	**Average Temp (C)**	**Average (mg/L)**	**n**	**% > 4 mg/L**	**Support Status**	**Average (mg/L)**	**n**	**Average > 0.025 mg/L?**
07/14/98	16.6	4	18.9	5.5	4	50%	PS	na	0	na
09/15/98	15.0	4	16.9	0.4	2	0%	NS	na	0	na
06/28/00	17.1	19	15.8	4.8	19	58%	FS	0.010	4	No
08/29/00	9.4	4	18.3	4.0	4	50%	PS	na	0	Na
06/19/02	0	1	na	na	0	na	na	0.010	1	No
07/24/02	11.0	11	20.1	5.5	11	64%	FS	0.010	3	No
09/27/02	7.4	9	17.6	6.5	9	100%	FS	0.038	1	Yes
06/26/03	19.0	19	15.0	5.4	19	68%	FS	0.010	4	No
07/17/03	18.8	20	16.0	4.1	20	40%	PS	0.015	4	No
08/14/03	14.6	16	15.4	1.7	16	19%	NS	0.019	4	No
09/24/03	9.9	11	15.0	7.3	11	100%	FS	0.032	4	Yes
06/23/04	15.2	17	15.6	5.6	17	65%	FS	0.010	4	No
08/18/04	10.7	12	17.7	2.6	12	33%	PS	0.010	3	No
06/15/06	17.4	19	14.3	6.0	19	89%	FS	0.017	2	No
07/11/06	14.8	16	15.2	3.4	16	38%	PS	0.015	4	No
08/16/06	5.1	7	21.7	5.8	7	100%	FS	na	0	na
10/05/06	7.1	8	14.4	6.4	8	100%	FS	0.021	3	No

n = number of samples   na = not available
FS = Full Support; PS = Partial Support; NS = Non-Support

Based on the water quality criteria for dissolved oxygen for reservoirs designated beneficial use 3A, the reservoir showed a partial support status during five sampling events (July 1998, August 2000, July 2003, August 2004, and July 2006), and non-support status during two sampling events (September 1998 and August 2003). The average total phosphorous in the water column exceeded the total phosphorus indicator value of 0.025 mg/L during two sampling events, 0.038 mg/L in September 2002 and 0.032 mg/L in September 2003.

STORET Station 5932440- Brough Reservoir Mid-Lake

STORET data for station 5932440 (Brough Reservoir Mid-Lake), includes data from 12 depth profiles in addition to other chemistry results for a total of 15 sampling events over the study period. The parameters of interest for evaluation of the water quality of Brough Reservoir as related to the impaired designated beneficial use (cold water fishery), due to low dissolved oxygen are listed in **Error! Reference source not found.** and summarized in Table 19.

Table 19
STORET Summary for Brough Reservoir Mid Lake (5932440)

				Dissolved Oxygen				**Total Phosphorus**		
Date	**Depth (m)**	**n**	**Average Temp (C)**	**Average (mg/L)**	**n**	**% > 4 mg/L**	**Support Status**	**Average (mg/L)**	**n**	**Average > 0.025 mg/L?**
07/14/98	8.6	2	19.7	5.8	2	100%	FS	0.019	2	No
09/15/98	7.3	2	18.1	4.0	2	50%	PS	0.033	2	Yes
06/28/00	9.3	2	18.9	5.9	2	100%	FS	0.015	2	No
07/24/02	7.2	8	22.0	7.1	8	100%	FS	0.010	1	No
09/27/02	9.5	11	17.7	6.5	11	100%	FS	0.051	2	Yes
06/26/03	15.5	17	15.2	5.5	17	65%	FS	0.010	1	No
07/17/03	2.8	4	24.1	7.0	4	100%	FS	0.010	1	No
08/14/03	8.8	10	17.8	3.3	10	40%	PS	0.010	2	No
09/24/03	1.3	3	18.6	9.4	3	100%	FS	0.034	1	Yes
06/23/04	8.1	10	17.6	6.5	10	90%	FS	0.010	1	No
08/18/04	5.4	7	20.3	4.5	7	71%	FS	0.010	2	No
06/15/06	13	14	15.8	7.0	14	100%	FS	0.010	2	No
07/11/06	10.7	12	16.7	4.0	12	42%	PS	0.010	1	No
08/16/06	13.4	15	16.9	2.8	15	40%	PS	0.010	1	No
10/05/06	3.6	5	14.7	7.6	5	100%	FS	0.023	2	No

n = number of samples   na = not available
FS = Full Support; PS = Partial Support; NS = Non-Support

Based on the water quality criteria for dissolved oxygen for reservoirs designated beneficial use 3A, the reservoir showed a partial support status during four sampling events (September 1998, August 2003, July 2006 and August 2006). Dissolved oxygen non-support status was not identified for the reservoir at this sampling location. The average total phosphorus in the water column exceeded the total phosphorus indicator value of 0.025 mg/L during three sampling events (0.0325 mg/L in September 1998, 0.0505 mg/L in September 2002, and 0.034 mg/L in September 2003).

STORET Station 5932450- Canal Above Brough Reservoir

All applicable STORET data for Station 5932450 are provided in **Error! Reference source not found.** and summarized in Table 20.

Table 20
STORET Summary for Canal Above Brough Reservoir (5932450)

Date	Temp (C)	DO (mg/L)	DO < 6.5	Total Phosphorus (mg/L)	Total Phosphorus > 0.05 mg/L?
07/14/98	21.8	7.8	No	0.054	Yes
09/15/98	21.0	7.5	No	0.063	Yes
06/28/00	19.4	6.7	No	0.038	No
11/13/02	2.1	11.0	No	na	na
01/28/03	0.3	12.41 SO		0.023	No
03/04/03	3.1	10.8	No	0.233 SO	
04/29/03	13.1	8.7	No	0.034	No
05/13/03	16.4	7.5	No	0.010	No
06/11/03	20.1	7.9	No	0.029	No
07/17/03	20.1	7.7	No	0.042	No
06/23/04	16.1	7.6	No	0.168	Yes
07/21/05	19.2	7.5	No	0.010	No
08/18/05	16.0	7.8	No	0.097	Yes
09/14/05	16.8	8.3	No	0.032	No
10/12/05	14.8	8.7	No	0.010	No
11/09/05	9.1	9.3	No	0.010	No
12/14/05	-0.2	11.0	No	0.010	No
01/18/06	-0.2	12.19 SO		0.010	No
02/15/06	0.0	11.2	No	0.010	No
03/15/06	8.7	9.8	No	0.010	No
04/12/06	20.8	6.6	No	0.010	No
04/26/06	21.9	8.1	No	0.010	No
05/10/06	21.4	6.4	Yes	0.010	No
05/24/06	14.0	8.7	No	0.269 SO	
06/07/06	26.3	7.0	No	0.027	No
06/15/06	15.2	8.7	No	0.058	Yes
06/21/06	26.5	8.5	No	0.010	No
07/11/06	20.3	7.7	No	0.191	Yes
08/02/06	17.8	9.2	No	na	na
11/07/06	7.3	9.7	No	0.023	No

n = number of samples na = not available SO = Suspected Outlier
FS = Full Support; PS = Partial Support; NS = Non-Support

The dissolved oxygen standard of 6.5 mg/L was not met once during the period of study on May 10, 2006 with a DO concentration of 6.44 mg/L. Total phosphorus input to Brough reservoir exceeds the indicator value of 0.05 mg/L during six sampling events out of 26 measurements (0.054 mg/L in July 1998, 0.063 mg/L in September 1998, 0168 mg/L in June 2004, 0.097 mg/L in August 2005, 0.058 mg/L in June 2006, and 0.191 in July 2006).

No canal flow data were provided for this STORET station.

4.1.3 Pollutant Loads

The annual total phosphorus load to Brough Reservoir was estimated through a statistical analysis of available flow data collected by the River Commissioner at the Ouray Extension gage and total phosphorus concentration data collected at Ouray Canal above Brough Reservoir station 5932450. The steps conducted in calculating the annual average load were:

1. Compile all available flow and concentration data
2. Synthesize flow information on dates when flows were not measured
3. Apply range of statistical methods to define daily loads
4. Select results of statistical method with lowest uncertainty, and calculate annual load as the sum of the daily loads

<u>Compile all available flow and concentration data</u>

Ten tributary concentration measurements were available that corresponded with the longest continuous flow record and after one outlier was removed, covering the time frame January 28, 2003 to October 12, 2005. Continuous daily flow measurements from the Ouray Extension Parshall flume were available covering the time frame April 1, 2001 to October 30, 2005.

<u>Synthesize flow information on dates when flows were not measured</u>

The statistical measures available for estimating annual load require daily stream flow measurements. Two small data gaps existed in the longest available continuous flow record, requiring that tributary flows for these data be estimated. Because the data gaps were of short duration (consisting of one day), linear interpolation between the nearest available dates of flow measurement was used to synthesize flows for the days when measurements were not available.

Apply range of statistical methods to define daily loads

The third step in estimating annual phosphorus loads consisted of applying a range of candidate statistical methods designed to estimate loads from continuous flow and discrete concentration data. The three methods applied were:

- Minimum variance unbiased estimator (MVUE) regression
- Beale's ratio estimator
- Aggregate method

Daily phosphorus loads were generated using each of the above methods for the entire period of flow record.

Select results of statistical method with lowest uncertainty

An evaluation was made regarding which of the above three statistical techniques for load estimation was most appropriate for Brough Reservoir. The Aggregate method estimator had the lowest standard error of its estimate, and was selected as the most appropriate approach. The best estimate of the annual phosphorus loading rate for Brough Reservoir is 298 kg/yr (Table 21).

Table 21
Annual Average Phosphorus Load Using the Aggregate Method

Method	Aggregate method
Annual TP Load (kg/yr)	298

4.1.4 Source Assessment

There are no point sources of pollution in Brough Reservoir's watershed, all existing pollutants originate from nonpoint sources. Current nonpoint sources in the watershed in order of significance include in-lake sources, canal erosion, animal waste, and recreational sources. An adaptive management approach was chosen as the most appropriate means to address these sources due to the uncertainty associated with their diffuse and highly variable nature and the assurance of future data collection to measure progress towards the identified load reduction goals.

Source Identification

There are several potential mechanisms by which phosphorus can enter the water column from sources within and external to Brough Reservoir. The following sections describe these sources in more detail and provide an approximation of the relative magnitude of the loading from each source to Brough Reservoir.

Internal Loading

Bottom sediments have long been acknowledged as a source of phosphorus to the overlying waters of lakes and reservoirs (Chapra, 1997). This is particularly true in lakes and reservoirs in which anaerobic conditions occur in the hypolimnion. Under anaerobic conditions, phosphorus in the sediments can be converted into soluble forms that are more available for algae growth. The soluble phosphorus can then be released into the overlying water column. When mixing occurs during spring and fall turnover, the soluble phosphorus can be carried into the upper water column where it is utilized by algae for growth.

The process by which the bottom sediments interact with the overlying water column is controlled by the length and severity of anoxia in the hypolimnion, the chemical constituents and phosphorus content of the sediments and the surface area of anoxic bottom sediments. Brough Reservoir experiences short periods of anoxia in the hypolimnion during the late summer months and increasing phosphorus concentrations near the lake bottom as shown by water column profile data so internal loading is characterized as a moderate source of phosphorus into Brough Reservoir.

Canal Erosion

Brough Reservoir is fed by the Ouray Valley Canal, a manmade conveyance that transports water from the Whiterocks River 29 miles to the Reservoir. Over the course of this distance the canal changes characteristics in relation to the geology and landforms over which it flows. The canal begins on a terrace of unconsolidated glacial outwash that consists primarily of cobbles and gravels that has low erodibility but quickly changes in the vicinity of the Merkley drop to a finer and more erodible sand and silt type soil. South of Lapoint the Canal then flows through a bedrock dominated channel where the majority of sediments settle out and deposited until it finally reaches the Reservoir. Since the Canal is a manmade structure the natural geomorphic principles that form and maintain stream channels do not apply. The Canal is designed and maintained to strictly convey flows to downstream water right holders. However, a significant threat to canal maintenance and downstream water quality is the imminent failure of the Merkley drop structure northwest of Tridell. Currently, water in the canal cascades over a concrete structure to a 100 foot plus drop and has seriously eroded to form an immense headcut that threatens the integrity of the drop structure. If this structure were to fail it would likely initiate a rapid migration of the headcut and introduce tons of sediment into the Canal. It is recommended that the drop be stabilized in the near future to prevent a catastrophic failure and ultimately cost much more to repair.

Animal Waste

Animal waste refers to the excreta of wildlife of livestock that typically contains high concentrations of available nutrients, particularly phosphorus. If the animal waste is deposited or washes into a waterbody the nutrients it contains are released into the water for algal uptake and growth. Based on a site visit along the Ouray Valley Canal and Brough Reservoir there appears to be minimal risk of animal waste loading.

Recreational Sources

Human caused recreational sources include litter and human waste. Although the Reservoir provides excellent fishing opportunities it does not receive heavy use due to its remote location and the prevalence of other more accessible and popular fishing spots nearby. Although recreational sources are currently not considered a significant pollutant source, the lack of trash receptacles and restrooms could lead to pollution problems in the future if the Reservoir becomes more popular. At a minimum we recommend signage indicating that no facilities are available at the Reservoir and to pack out all litter.

4.1.5 Linkage Analysis

The BATHTUB water quality model was used to define the relationship between external phosphorus loads and resulting concentrations of total phosphorus, chlorophyll a, and dissolved oxygen in Brough Reservoir. The model application is described in the following sections, including information on:

- Model selection
- Model inputs
- Model calibration
- Model application for TMDL development

<u>Model Selection</u>

The BATHTUB model (Walker, 1985) was selected to address phosphorus impairments to Brough Reservoir. This model was selected because it does not have extensive data requirements (and can therefore be applied with existing data), yet still provides the capability for calibration to observed lake data. BATHTUB has been used previously for several reservoir TMDLs nationwide, and has been cited as an effective tool for lake and reservoir water quality assessment and management, particularly where data are limited (Ernst et al., 1994).

The model was used to predict the relationship between phosphorus load and resulting in-lake phosphorus and chlorophyll a concentrations, as well metalimnetic oxygen demand.

<u>Model Inputs</u>

This section provides an overview of the model inputs required for BATHTUB application, and how they were derived. The following categories of inputs are required for BATHTUB:

- Model Options
- Global Variables
- Reservoir Segmentation
- Tributary Loads

<u>Model Options</u>

BATHTUB provides a multitude of what are termed “model options”. These options allow the modeler to tailor the modeling approach to address only those constituents of concern, using model equations that best reflect site-specific conditions. The BATHTUB model options selected for Brough Reservoir are shown in Table 22, with the rationale for these options discussed below. In general, the default model options specified by BATHTUB were selected unless site-specific information indicated that a different approach was more applicable.

No conservative substance was being simulated, so this option was not needed. The second order option was selected for phosphorus as the model option for BATHTUB which is the default approach in BATHTUB. Total nitrogen was not simulated, because the reservoir experiences periods of phosphorus limitation and because phosphorus is more easily controlled from a management perspective than nitrogen sources. Chlorophyll a was simulated using the default BATHTUB approach. Water transparency was not simulated. The Fischer numeric dispersion model was selected, which is the default approach in BATHTUB. Phosphorus calibrations were based on lake concentrations. The use of availability factors was not required, and estimated concentrations were used to generate mass balance tables.

Table 22
BATHTUB Model Options for Brough Reservoir

MODEL	MODEL OPTION
Conservative substance	**Not computed**
Total phosphorus	2^{nd} order
Total nitrogen	Not computed
Chlorophyll-a	Phosphorus, Light, T
Transparency	Not computed
Longitudinal dispersion	Fischer-numeric
Phosphorus calibration	Concentrations
Nitrogen calibration	None
Error analysis	Not computed
Availability factors	Ignored
Mass-balance tables	Use estimated concentrations

Global Variables

The global variables required by BATHTUB consist of:

- The averaging period for the analysis
- Precipitation, evaporation, and change in lake levels
- Atmospheric phosphorus loads

BATHTUB is a steady state model, whose predictions represent concentrations averaged over a period of time. A key decision in the application of BATHTUB is the selection of the length of time over which inputs and outputs should be modeled. The length of the appropriate averaging period for BATHTUB application depends upon the nutrient residence time, which is the average length of time that phosphorus spends in the water column before settling or flushing out of the lake. Guidance for the BATHTUB model recommends that the averaging period used for the analysis be at least twice as large as the nutrient residence time for the lake of interest. The nutrient residence time for Brough Reservoir was approximately three and half months, so an annual averaging period was used (the BATHTUB averaging period is usually selected as 2-3 times the nutrient residence time, so the default averaging period should be 7-10.5 months; however, given the nature of the flow inputs to Brough, with several months of zero loading, use of an annual averaging period will give essentially identical results to the use of 10 month averaging period).

Precipitation inputs for Brough Reservoir were taken from the observed precipitation data, scaled to the appropriate simulation period. This resulted in a precipitation value of 23 inches for Brough Reservoir. The values selected for precipitation and change in lake levels have little influence on model predictions. Atmospheric phosphorus loads were specified using default values provided by BATHTUB.

Reservoir Segmentation

BATHTUB provides the capability to divide the reservoir under study into a number of individual segments, allowing prediction of the change in phosphorus concentrations over the length of the reservoir. BATHTUB requires that a range of inputs be specified for each segment. These include segment surface area, length, total water depth, depth of thermocline and mixed layer; and observed water quality data to support model calibration. A single-segment approach was selected for Brough Reservoir, as the size of the reservoir and review of available data did not indicate the presence of significant longitudinal variation to justify the use of multiple model segments.

Tributary Loads

BATHTUB requires information describing tributary flow and nutrient concentrations into each reservoir segment. The approach used to estimate flows and loads was discussed previously.

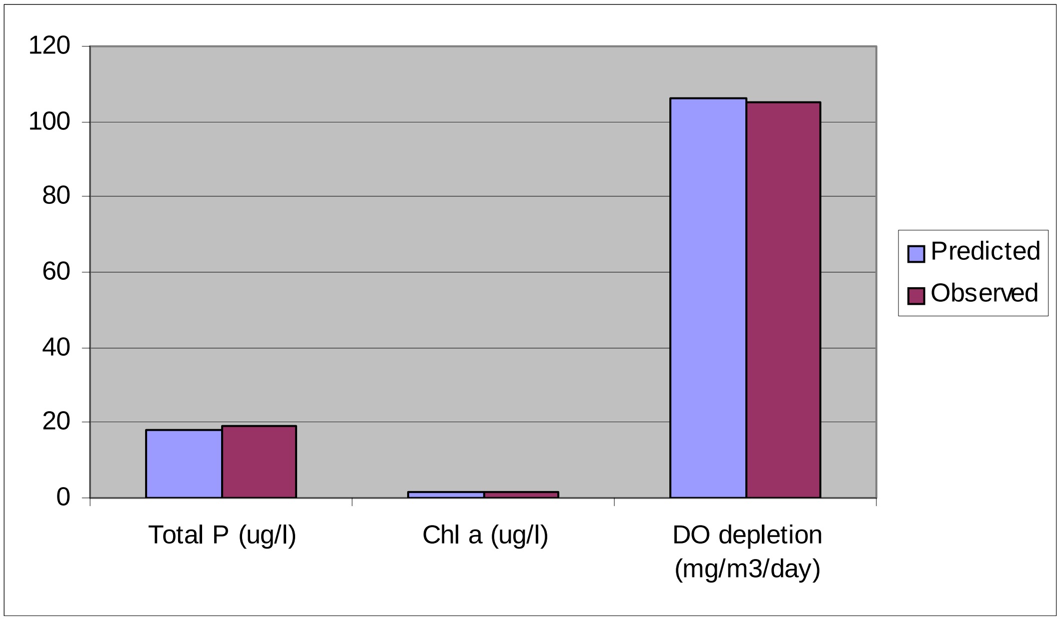
BATHTUB Calibration

BATHTUB model calibration consists of:

1. Applying the model with all inputs specified as above
2. Comparing model results to observed phosphorus data
3. Adjusting model coefficients to provide the best comparison between model predictions and observed phosphorus data.

The BATHTUB model was applied with the model inputs as specified above. The model calibration period represented an average condition across all years for which data were available. BATHTUB was first calibrated to match the observed reservoir total phosphorus concentrations. The resulting predicted lake average total phosphorus concentration was 0.018 mg-P/L, compared to an observed average of 0.019 mg-P/L. BATHTUB results were then compared to observed chlorophyll a. The predicted chlorophyll a concentration was 0.0015 mg/L, compared to an observed average of 0.0014 mg/L. A calibration adjustment factor of 0.3 was used to bring the predicted chlorophyll a concentration in alignment with the observed data. Finally, the predicted metalimnetic oxygen depletion rate was compared to the observed. The initial predicted oxygen depletion rate was 36 mg O2/m3/day, compared to an observed average of 105 mg O2/m3/day. The oxygen depletion rate was adjusted via the calibration process to a value of 106 mg O2/m3. A comparison of final model predictions vs. observed data is shown in Figure 10. This comparison represents an acceptable model calibration.

Figure 10
BATHTUB Model Calibration Results for Brough Reservoir



Model application for TMDL development

The calibrated BATHTUB model was applied to determine the level of phosphorus loading reduction required to maintain compliance with the dissolved oxygen target (specified as a dissolved oxygen concentration above 4 mg/L at the 50% depth in the water column). The most critical period for oxygen assessment will occur just prior to fall turnover, when the lake has been stratified for the maximum possible time. The BATHTUB output, which is specified as an oxygen depletion rate, can be converted into a dissolved oxygen concentration suitable for comparison to the target, via the following equation:

DO at turnover =

DO at onset of stratification –

(DO depletion rate) x number of days of stratification (1)

Equation 1 can be rearranged to solve for a target oxygen depletion rate, i.e. one that will lead to compliance with the dissolved oxygen target of 4.0 mg/L just at the onset of stratification:

Target DO depletion rate = (DO at turnover – 4.0)/

number of days of stratification (2)

The available data were examined and the average dissolved oxygen at the onset of stratification was calculated as 7.8 mg/L while an approximate duration of stratification was assumed at 122 days (June 1 to October 1). Entering these values into Equation 2 results in a target DO depletion rate of 0.031 mg/L/day (31 mg O_2/m^3/day).

The BATHTUB model was then run to determine the maximum allowable phosphorus load that would maintain compliance with the target DO depletion rate. This target loading was 9 kg/yr, corresponding to a 97% reduction in existing loads.

This level of loading reduction is expected to be unattainable in the Brough Reservoir watershed.

4.1.6 Trophic State Assessment

The Carlson Trophic State Index (TSI) is used to describe the biological productivity of a lake or reservoir. Trophic states (Table 23) are defined as the total weight of living biological material at a given time, which is estimated independently by measurements of chlorophyll-a, total phosphorus, and secchi depth. TSI values based on chlorophyll a are considered the best indicator of biological activity in lakes.

Table 23
Carlson Trophic State Index

Trophic state	TSI value	Character
Oligotrophic	0-30	Clear water, high DO throughout the year in the hypolimnion
Oligotrophic	30-40	Clear water, possible periods of limited hypolimnetic anoxia
Mesotrophic	40-50	Moderately clear water, increasing chance of hypolimnetic anoxia in summer, cold water fisheries “threatened”, supportive of warm water fisheries
Eutrophic	50-60	Decreased transparency, anoxic hypolimnion, macrophyte problems
Eutrophic	60-70	Blue-green algae dominance, algal scums possible, extensive macrophyte problems
Hypereutrophic	70-80	Heavy algal blooms possible throughout summer, dense macrophyte beds, Algal scums, summer fish kills, few macrophytes due to algal shading; rough fish dominance

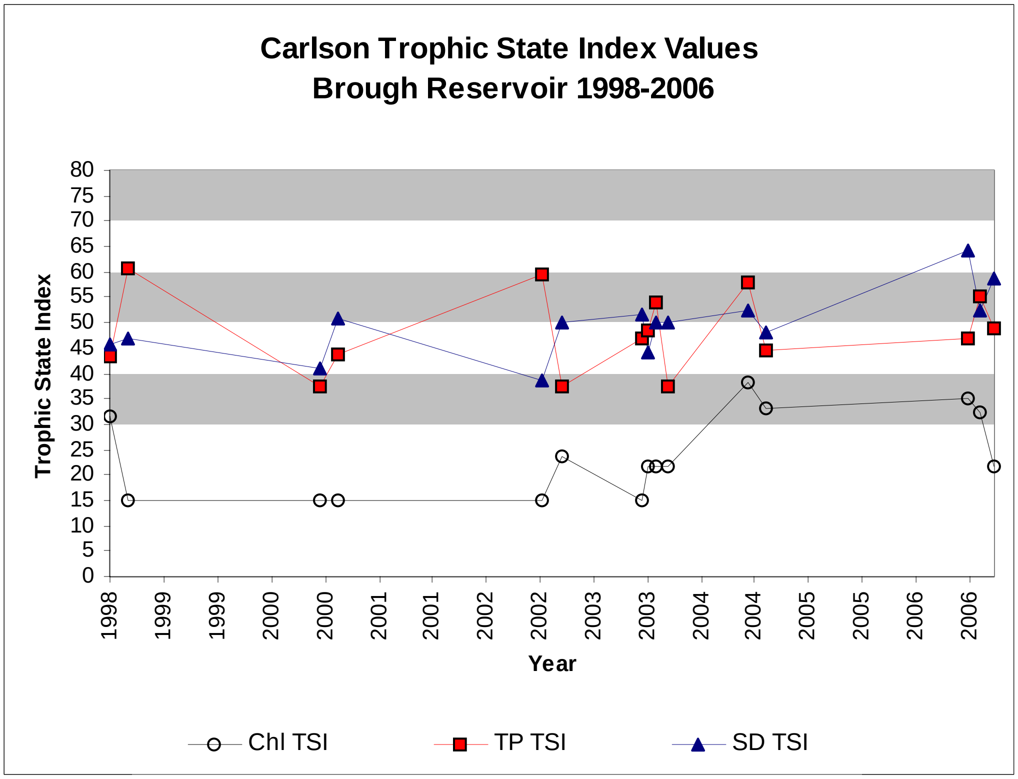
Trophic indices for Brough Reservoir based on chlorophyll *a* concentrations from 1998 to 2006, ranged from 15 to 36 with an average of 24 demonstrating that it is an oligotrophic system having clear water with limited periods of hypolimnetic anoxia (see Table 24). In contrast, trophic indices based on Secchi Depth concentrations (range from 46 to 58 with an average of

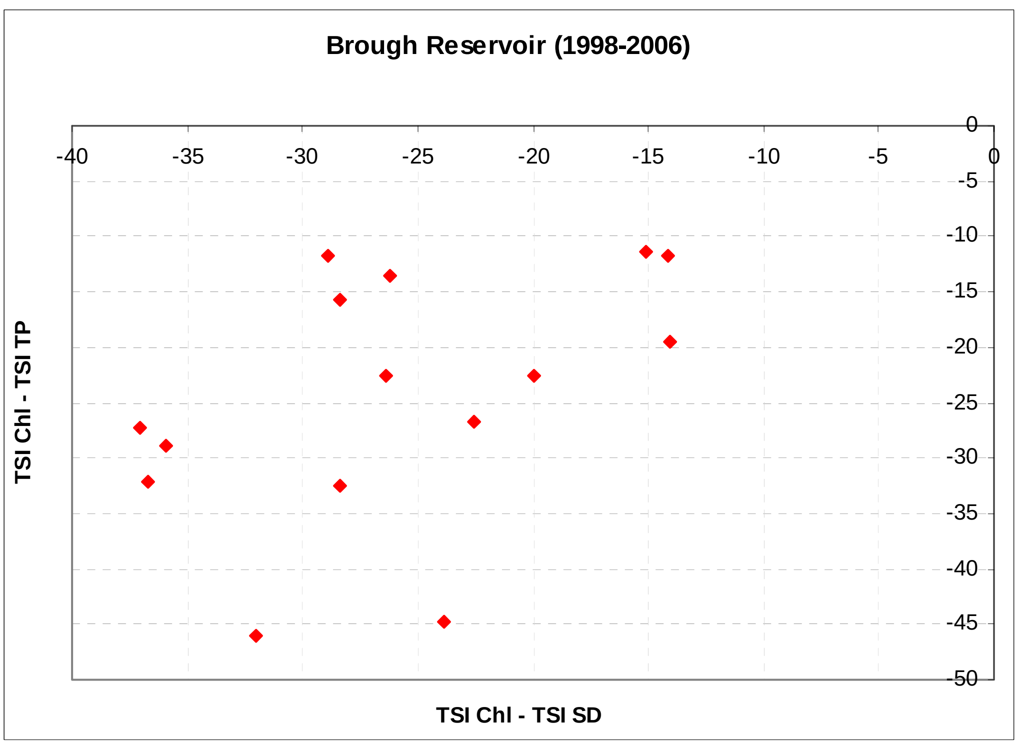
49) and Total Phosphorous (range from 41 to 52 with an average of 48) indices indicate the reservoir is mesotrophic with moderately clear water and hypolimnetic anoxia in the summer. There is no discernable trend whether the system is degrading or improving during the study period (Figure 11).

Table 24
Brough Reservoir Trophic State Index

Year	TSI (CHL)	TSI (SD)	TSI (TP)
1998	23	46	52
2000	15	46	41
2002	19	44	48
2003	20	49	47
2004	36	50	51
2006	30	58	50
Average	24	49	48

Figure 11
Brough Reservoir Trophic State Index



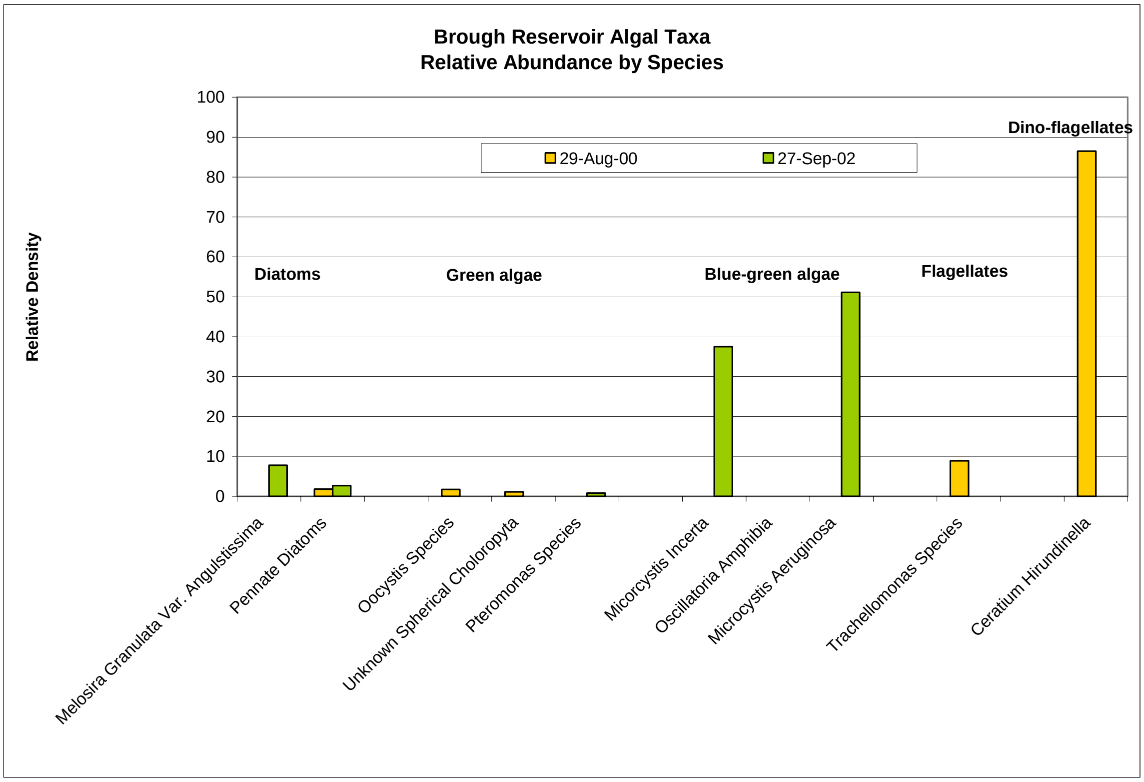


The majority of plotted points fall within the negative x and y coordinate systems. This quadrant suggests transparency could be attributed to non-algal related turbidity such as color or small particles and something other than phosphorus is limiting algal growth (Carlson, 1992). It may also indicate that phosphorus is not the limiting nutrient. To examine the potential limiting nutrient for phytoplankton productivity, the Nitrogen to Phosphorus (N:P) ratios were calculated using a "pseudo" N:P ratio as (NH_3 +NO_2+NO_3)/TP. This is called a "pseudo" ratio because organic nitrogen data were unavailable, one of the components that comprises total nitrogen. Thus, the true N:P ratio is underestimated and over-predicts the occurrence of nitrogen limitation. If phosphorus limitation occurs using the pseudo-ratio then the amount of phosphorus limitation that exists using the true ratio would be even greater. When the average “pseudo” N:P ratio for all samples was greater than 7.2 (the theoretical division between nitrogen and phosphorus limitation), the reservoir is considered phosphorus limited. For Brough Reservoir, the average N:P ratio over the study period was calculated as 8 with 74% of the samples greater than 7.2 (the theoretical division between nitrogen and phosphorous limitation) indicating it is phosphorous limited.

4.1.7 Phytoplankton Assessment

Phytoplankton data were collected from the euphotic zone in September 2000 and 2002 (Figure 12). In 2001, the phytoplankton community was dominated by the dino-flagellates (*Ceratium hirundinella*) and flagellates (*Trachelomonas species*) comprising 95% of the sample. In 2002, the majority of the sample contained blue green algae (89%) species *Microcystis ancerta* and *Microcystis aeruginosa,* algal indicators of eutrophy. Though these 2 samples reflect the biological condition at a point in time they do not address seasonal phytoplankton succession nor can definitively address phytoplankton species composition changes in relation to trophic status over time.

Figure 12
Brough Reservoir Algal Taxa



4.1.8 Sediment Oxygen Demand

The rate of sediment oxygen demand (SOD) occurring in each reservoir can be estimated from historically observed data defining the decrease in hypolimnetic dissolved oxygen over the course of a summer (i.e. DO depletion rates).

SOD (g/m2/day) = [Observed DO depletion rate – DO depletion due to water column demand] x Water Depth.

The above equation is based on the fact that oxygen depletion in the hypolimnion is caused by two separate sources: 1) oxygen depletion due to water column BOD and algal respiration, and 2) oxygen depletion due to SOD. The observed oxygen depletion rate reflects the combined effect of both sources. The SOD component can therefore be calculated by subtracting the water column component from the observed total. Chapra (1997) indicates that it can be assumed that SOD is the primary cause of hypolimnetic oxygen depletion, such that the water column contribution can be ignored in the equation above. SOD calculations for Brough Reservoir are provided in Table 25.

Table 25
Brough Reservoir SOD Calculations

Observed DO Depletion rate ($g/m^3/day$)	Hypolimnetic Depth (m)	Estimated SOD ($g/m^2/day$)
0.105	2.9	0.30

While there are no definitive guidelines, an estimated SOD of 0.3 $g/m^2/day$ would be considered somewhere between oligotrophic and mesotrophic.

4.1.9 Seasonality

These TMDL calculations were conducted with an explicit consideration of seasonal variation. The BATHTUB model is designed to evaluate seasonal to annual loads. Annual loads were calculated by summing the individual daily loads over the course of a year, and fully capturing seasonal variability. The annual loading analysis that was used is appropriate due to the long response time between phosphorus loading and biotic response.

4.2 Red Fleet Reservoir

4.2.1 Stations and Data

For the period of study, DWQ provided water quality data from four STORET stations near Red Fleet Reservoir for this TMDL water quality study. These stations and the years of available data are listed in Table 26.

Table 26
STORET Stations Containing Water Quality Data for the Period of Study

STORET	Type	Description	Sample Years
4937860	River/Stream	BIG BRUSH CREEK AT U44 CROSSING	1996 1997 1999 - 2001 2003 - 2006
4937930	River/Stream	Big Brush Creek above Phosphate Plant	2003 – 2005
5937650	Lake	RED FLEET RESERVOIR ABOVE DAM 01	1997 1999 2001 2003 2005 - 2006
5937660	Lake	RED FLEET RESERVOIR MIDLAKE 002	1997 1999 2001 2003 2005

The raw data and statistical summaries of available data collected at the four STORET stations described above for the period of study are provided in **Error! Reference source not found.**. For each station, the data are tabulated from the raw output and followed by descriptive statistics. The statistics list the number, minimum, maximum, mean, standard deviation, and the mean plus 2 standard deviations (for outlier analysis). Laboratory detection limits for each parameter were provided by DWQ. Where results were below the laboratory detection limit, one-half the detection limit was entered for statistical analyses. It is important to note that although water quality exceedences are displayed in the table, it is not intended to be used in comparison to 303(d) listing criteria.

<u>Outlier Analysis and Treatment of Results Below Laboratory Detection Limits</u>

Results that fall outside the control limits of plus two standard deviations from the mean were judged to be suspected outliers and removed from further statistical analysis.

For reservoir sampling, DWQ collects depth profile data using a data sonde that records temperature, pH, specific conductivity, and dissolved oxygen at approximately 1-meter intervals through the water column. Combined with depth profile sampling are grab samples collected at the surface, 1 meter above the thermocline, 1 meter below the thermocline, and 1 meter from the bottom of the reservoir.

Parameters of interest to this TMDL water quality study and the number of reservoir samples collected during the period of study are listed in Table 27.

Table 27
Parameters and Number of Results for the Red Fleet Reservoir STORET Stations for the Period of Study

Parameter	5937650 Red Fleet Res Above Dam	5937660 Red Fleet Res Mid Lake
Datalogger Profiles	Year – No. of Profiles: 2001 - 2 2003 - 4 2005 - 8 2006 - 6	Year – No. of Profiles: 2001 - 2 2003 - 4 2005 - 2
Number of Results (excluding outliers):		
Depth	598	168
Water Temperature	598	168
Dissolved Oxygen	598	168
Dissolved Oxygen Saturation	582	160
Total Phosphorus	78	12
Chlorophyll	23	12
Depth Secchi Disk	23	10
Nitrogen as Nitrate + Nitrite	84	19
Nitrogen as Ammonia	81	20

Additional data are available for the two tributary stations above Red Fleet Reservoir: Big Brush Creek at U44 Crossing (STORET 4937860) and Big Brush Creek above Phosphate Plant (STORET 4937930). For the period of study, the years of available data from these stations are listed in Table 26. Parameters of interest to this TMDL water quality study and the number of tributary samples collected at these stations during the period of study are listed in Table 28.

Table 28
Parameters and Number of Results for Red Fleet Reservoir Tributary STORET Stations for the Period of Study

Parameter	4937860 Big Brush Creek at U44 Crossing	4937930 Big Brush Creek above Phosphate Plant
Number of Results (excluding outliers):		
Water Temperature	41	3
Dissolved Oxygen	39	3
Total Phosphorus	37	3
Dissolved Phosphorus	28	0
Nitrogen as Nitrate + Nitrite	4	0
Nitrogen as Ammonia	32	0
Total Suspended Solids	39	3
Turbidity	33	3

Simplot Phosphate, LLC Monitoring Data

Simplot Phosphates, LLC operates a tailings impoundment facility at its phosphate mine, which is located approximately 18 kilometers north of Vernal in Uintah County, Utah. The tailings impoundment operates with a groundwater discharge permit granted by the State of Utah Division of Water Quality (DWQ). The permit allows only certain materials to be discharged to the tailings impoundment: 1) solids and water from the phosphate ore milling operation; 2) domestic wastewater that has been treated to meet secondary water quality standards; and 3) stormwater runoff from the area that naturally drains into the impoundment. The impoundment is located mainly over an outcrop of the Moenkopi Shale, a formation with generally low permeability containing gypsum and other soluble salts. Wastewater from the ore milling process is of better quality than the groundwater in the Moenkopi formation. The permit does not require lining of the impoundment, but there is a potential that this facility could cause increased leaching of soluble salts in the underlying Moenkopi Shale (State of Utah Division of Water Quality, Utah Water Quality Board Groundwater Discharge Permit No. UGW470001 issued to Simplot Phosphates LLC, effective date: June 17, 2005). Water quality monitoring required by permit includes:

1) Tailings Impoundment: Grab samples of water from the tailings impoundment are collected annually, during the third quarter. These samples are tested in the field for pH, temperature and specific conductance and analyzed by a State-certified laboratory for TDS, sodium, calcium, potassium, magnesium, chloride, sulfate, bicarbonate, carbonate, dissolved phosphorous, and uranium.
2) Big Brush Creek: Grab samples are collected at two locations designated as BCF and BC191 (see Map 12). Grab samples are collected quarterly from these locations along with stream flow rates. Surface water samples are analyzed for total dissolved solids (TDS) gross alpha and gross beta radiation, combined radium (Ra-226 and Ra-228) isotopes, iron, and total phosphorous.
3) Monitoring Wells: Simplot Phosphate LLC has installed 16 compliance-monitoring wells to monitor groundwater quality in several aquifers and the performance of cutoff slurry

walls that have been constructed in three filled drainages to prevent excessive discharge of tailings water from the impoundment. Upgradient wells are sampled semi-annually or annually; downgradient wells are sampled quarterly. Groundwater protection levels have been established for the 10 existing downgradient monitoring wells.

Water quality data were provided by DWQ for each of these sampling locations for review. Numerical values of "0" were reported for several sampling events in the data provided by DWQ. In the following discussions, it has been assumed that "0" represents some value below the minimum detection limit for the laboratory analytical method employed. In evaluating the water quality of Red Fleet Reservoir, the parameter of primary interest appears to be is phosphorous, as it may be related to low dissolved oxygen, a recognized impairment to the designated beneficial use (cold water fishery) of the reservoir. Total phosphorous concentrations are tabulated for each monitoring location and presented in **Error! Reference source not found.**.

Tailings Impoundment Data:
Water is sampled from a barge in the tailings impoundment. Total phosphorous data has been reviewed for the four available monitoring events: May 2004, July 2004, August 2005 and September 2006. Total phosphorous concentrations ranged from a low of 0.05 mg/L in July 2004 to a high of 0.21 mg/L in May 2004.

Big Brush Creek Data:
Big Brush Creek sampling stations are located between the gorge and the mine road crossing (BCF) and downstream at the Highway 191 crossing (BC191). A surface water quality action level has been established at 0.05 mg/L. Available water quality data from quarterly sampling events were reviewed for an eight-year period from August 1998 through September 2006. Total phosphorous concentrations ranged from 0 mg/L to 0.1 mg/L in water samples collected from the BCF location. The water quality action level for phosphorous was exceeded twice during that period: once on May 1, 1999 (0.09 mg/L) and again on March 6, 2006 (0.1 mg/L). Total phosphorous concentrations ranged from 0 mg/L to 0.13 mg/L in water samples collected from BC191. The water quality action level was exceeded three times during the same period: on August 1, 1998 (0.09 mg/L); on May 1, 1999 (0.13 mg/L); and on June 23, 2005 (0.06 mg/L).

Compliance Monitoring Well Data:

Background groundwater quality is monitored in 4 upgradient wells: WW-D, screened in the Weber Aquifer; GW-2 and GW-4, screened in the Moenkopi Formation; and GE-1, screened in the Alluvial Aquifer. Available quarterly groundwater quality monitoring data were reviewed for two upgradient wells (WW-D and GE-1) and 10 downgradient wells: WW-E (Weber Aquifer); CO-2, CO-4, and GE-6 (Moenkopi Formation); CO-6, GE-2, GE-3, GE-4, and GE-5 (Alluvial Aquifer); and GR-1 (Gartra Member of the Chinle Formation).

Total phosphorous concentrations in upgradient wells ranged from 0 mg/L to 0.07 mg/L in WW-D and from 0.04 mg/L to 3.0 mg/L in GE-1. Groundwater monitoring data indicate that groundwater in the shallow upgradient alluvial aquifer well (GE-1) has a high phosphorous content compared to the impoundment wastewater and several of the downgradient compliance monitoring wells on the mine property.

Groundwater protection levels have been established for each of the 10 downgradient monitoring wells on the mine property. These protection levels are based on: 1) the background mean plus 2 standard deviations; 2) the practical quantitation limit for the analytical method; or 3) the background mean concentration times the Groundwater Class multiplier factor.

Total phosphorous concentrations in samples collected from the downgradient wells screened in the Alluvial Aquifer ranged from 0 mg/L to 1.93 mg/L. Groundwater protection levels for phosphorous were exceeded twice during the 9-year monitoring period: once in July 1999 in a sample collected from CO-6 (0.95 mg/L), which exceeded the protection level of 0.90 mg/L; and once in August 1998, in a sample collected from GE-2 (1.93 mg/L), which exceeded the protection level of 1.6 mg/L.

Total phosphorous concentrations in samples collected from downgradient wells that are screened in the Moenkopi Formation ranged from 0 mg/L to 2.1 mg/L. Groundwater protection levels were exceeded three times during the period from August 1998 to August 2006. A sample collected from GE-6 in December 1998 contained 1.78 mg/L, which exceeded the groundwater protection level of 1.5 mg/L for that well. A sample collected from CO-2 in April 1999 contained 2.1 mg/L, which exceeded the groundwater protection level of 1.7 mg/L. A sample collected from CO-4 in May 1999 contained 0.33 mg/L total phosphorous, which exceeded the groundwater protection level of 0.1 mg/L for that well.

One downgradient, compliance monitoring well, WW-E, is screened within the Weber Aquifer. Total phosphorous concentrations ranged from 0 mg/L to 0.77 mg/L during the period from August 1998 to August 2006. Total phosphorous exceeded the groundwater protection level of 0.05 mg/L once in August 2001 with a concentration of 0.77 mg/L. Similarly, one downgradient compliance monitoring well is screened in the Gartra Member of the Chinle Formation (GR-1). Total phosphorous concentrations ranged from 0 mg/L to 0.11 mg/L for the period from December 1999 to August 2006. Total phosphorous exceeded the groundwater protection level of 0.05 mg/L one time at a concentration of 0.11 mg/L in August 2005.

Based on the noncompliance criteria incorporated in the groundwater discharge permit, none of the wells were out of compliance based on the reported groundwater protection level exceedences.

4.2.2 Summary of Impairment

<u>5937650 - Red Fleet Reservoir Above Dam</u>

STORET data for station 5937650 (Red Fleet Reservoir Above Dam), includes data from 20 depth profiles in addition to other chemistry results for a total of 24 sampling events over the study period. The parameters of interest and associated statistics for evaluation of the water quality of Red Fleet Reservoir as related to the impaired designated beneficial use (cold water fishery), due to low dissolved oxygen, are listed in **Error! Reference source not found.** and summarized in Table 29.

Table 29
STORET Summary for Red Fleet Reservoir Above Dam (5937650)

				Dissolved Oxygen				Total Phosphorus		
Date	**Depth (m)**	**n**	**Average Temp (C)**	**Average (mg/L)**	**n**	**% > 4 mg/L**	**Support Status**	**Average (mg/L)**	**n**	**Average > 0.025 mg/L?**
07/22/97	24.8	4	16.18	5.38	4	100%	FS	na	0	na
09/17/97	23.7	4	16.85	5.63	4	75%	FS	na	0	na
07/07/99	27.6	4	16.43	7.18	4	100%	FS	0.010	4	No
08/30/99	0.1	1	22.50	7.60	1	100%	FS	0.010	1	No
08/31/99	28.7	3	14.60	5.27	3	67%	FS	0.010	2	No
06/27/01	30.1	34	11.93	7.05	34	100%	FS	0.016	4	No
09/04/01	24.0	27	15.82	3.49	27	30%	PS	0.010	4	No
06/25/03	26.3	30	11.50	6.24	30	100%	FS	0.010	4	No
07/16/03	23.1	24	13.85	5.78	24	100%	FS	0.010	3	No
08/13/03	22.1	24	15.67	4.62	24	38%	PS	0.014	4	No
09/25/03	25.0	26	15.06	4.73	26	62%	FS	0.010	3	No
05/04/05	24.0	25	8.40	8.93	25	100%	FS	0.010	3	No
06/01/05	28.0	29	9.85	8.17	29	100%	FS	0.020	3	No
07/14/05	29.0	30	12.48	6.90	30	100%	FS	0.016	4	No
07/20/05	24.0	26	13.14	7.03	26	100%	FS	0.013	4	No
08/09/05	28.0	29	13.36	5.90	29	100%	FS	0.010	4	No
09/07/05	27.0	52	14.33	4.04	52	29%	PS	0.013	4	No
10/04/05	27.7	29	13.36	3.57	29	45%	PS	0.010	4	No
11/02/05	28.0	29	11.93	6.48	29	100%	FS	0.010	3	No
05/09/06	30.0	31	8.26	8.81	31	100%	FS	0.010	4	No
06/08/06	31.0	32	10.85	7.07	32	100%	FS	0.010	4	No
07/05/06	28.0	29	12.78	5.64	29	100%	FS	0.010	4	No
08/23/06	25.0	26	16.08	3.62	26	35%	PS	0.010	1	No
09/26/06	21.2	23	15.05	4.99	23	78%	FS	0.010	4	No
10/24/06	25.6	27	12.00	7.77	27	100%	FS	0.010	3	No

n = number of samples na = not available
FS = Full Support; PS = Partial Support; NS = Non-Support

Based on the water quality criteria for dissolved oxygen for reservoirs designated beneficial use 3A, the reservoir showed a partial support status during five sampling events (September 2001, August 2003, September 2005, October 2005, and August 2006). The reservoir did not show a non-support status due to low dissolved oxygen during the period of study. The total phosphorus indicator value of 0.025 mg/L was not exceeded during the period of study.

STORET 5937660 - Red Fleet Reservoir Mid Lake

STORET data for station 5937660 (Red Fleet Reservoir Mid Lake), includes data from 8 depth profiles in addition to other chemistry results for a total of 12 sampling events over the study period. The parameters of interest and associated statistics for evaluation of the water quality of Red Fleet Reservoir as related to the impaired designated beneficial use (cold water fishery), due to low dissolved oxygen, are listed in **Error! Reference source not found.** and summarized in Table 30.

Table 30
STORET Summary for Red Fleet Reservoir Mid Lake (5937660)

				Dissolved Oxygen				Total Phosphorus		
Date	**Depth (m)**	**n**	**Average Temp (C)**	**Average (mg/L)**	**n**	**% > 4 mg/L**	**Support Status**	**Average (mg/L)**	**n**	**Average > 0.025 mg/L?**
07/22/97	24.9	2	15.80	5.00	2	100%	FS	na	0	na
09/17/97	14.1	2	17.10	5.50	2	50%	PS	na	0	na
07/07/99	25.8	2	16.35	7.20	2	100%	FS	0.019	2	No
08/31/99	27.0	1	9.60	6.50	1	100%	FS	0.033	1	Yes
06/27/01	20.2	20	13.08	7.64	20	100%	FS	0.010	2	No
09/04/01	14.0	15	18.78	5.66	15	73%	FS	0.010	2	No
06/25/03	18.9	18	12.64	6.84	18	100%	FS	na	0	na
07/16/03	19.8	21	14.39	6.58	21	100%	FS	0.020	2	No
08/13/03	18.4	21	16.32	5.57	21	71%	FS	na	0	na
09/25/03	23.5	25	15.10	4.79	25	64%	FS	na	0	na
07/20/05	22.3	23	13.09	6.54	23	100%	FS	0.015	2	No
09/07/05	15.4	17	16.26	5.59	17	65%	FS	na	0	na

n = number of samples   na = not available
FS = Full Support; PS = Partial Support; NS = Non-Support

Based on the water quality criteria for dissolved oxygen for reservoirs designated beneficial use 3A, the reservoir showed a partial support status during one sampling event (September 1997). The reservoir did not show a non-support status due to low dissolved oxygen during the period of study. The average total phosphorous in the water column exceeded the total phosphorus indicator value of 0.025 mg/L once in August 1999 at 0.033 mg/L.

STORET 4937860 - Big Brush Creek at U44 Crossing

All applicable STORET data for Station 4937860 are provided in **Error! Reference source not found.** and summarized in Table 31.

Table 31
STORET Summary for Big Brush Creek at U44 Crossing (4937860)

Date	Temp (C)	DO (mg/L)	DO < 6.5	Total Phosphorus (mg/L)	Total Phosphorus > 0.05 mg/L?
07/22/97	13.60	6.30	Yes	na	
09/17/97	12.50	10.70	No	na	
04/28/99	na	na		0.066	Yes
07/07/99	16.80	8.50	No	0.026	No
08/31/99	15.90	9.00	No	0.088 SO	
08/16/00	14.59	8.68	No	0.010	No
09/20/00	11.05	10.53	No	na	
10/18/00	8.99	9.80	No	0.020	No
12/13/00	3.90	10.10	No	0.010	No
01/10/01	3.88	9.92	No	0.051	Yes
02/07/01	4.99	10.28	No	0.010	No
04/04/01	7.18	9.67	No	0.028	No
04/25/01	7.49	10.35	No	0.037	No
05/23/01	7.57	10.12	No	0.050	No
06/06/01	10.69	8.61	No	0.063	Yes
06/28/01	7.84	8.81	No	0.010	No
09/05/01	17.53	7.74	No	0.010	No
07/16/03	19.17	8.20	No	0.010	No
09/25/03	11.57	10.54	No	0.010	No
10/15/03	6.59	10.15	No	0.010	No
08/04/04	15.26	9.46	No	0.010	No
07/20/05	11.79	10.24	No	0.010	No
07/20/05	19.69	8.17	No	0.010	No
08/16/05	14.25	8.99	No	0.010	No
09/07/05	14.63	8.20	No	0.010	No
09/13/05	11.07	10.44	No	0.010	No
09/15/05	9.34	9.62	No	0.010	No
10/11/05	10.10	9.52	No	0.010	No
11/08/05	9.13	10.12	No	0.010	No
12/13/05	4.66	12.21 SO		0.010	No
01/17/06	3.42	12.09 SO		0.010	No
02/14/06	5.94	9.87	No	0.010	No
03/14/06	7.03	10.66	No	0.012	No
04/11/06	10.41	10.60	No	0.030	No
04/25/06	8.18	9.03	No	0.047	No
05/09/06	7.63	9.87	No	0.051	Yes
05/23/06	10.26	9.30	No	0.1 SO	
06/06/06	15.27	8.44	No	0.010	No
06/20/06	16.79	8.27	No	0.010	No

08/02/06	13.29	10.91	No	0.030	No
10/03/06	12.86	8.69	No	0.010	No
11/07/06	9.38	9.37	No	0.010	No

n = number of samples na = not available SO = Suspected Outlier
FS = Full Support; PS = Partial Support; NS = Non-Support

The dissolved oxygen standard was less than 6.5 mg/L once during the period of study in July 1997. The total phosphorus indicator of 0.05 mg/L was exceeded during four sampling events (0.066 mg/L in April 1999, 0.051 mg/L in January 2001, 0.063 mg/L in June 2001, and 0.051 mg/L in May 2006).

No flow data were provided for this STORET station.

STORET 4937930 – Big Brush Creek above Phosphate Plant

All applicable STORET data for Station 4937930 are provided in **Error! Reference source not found.** and summarized in Table 32.

Table 32
STORET Summary for Big Brush Creek above Phosphate Plant (4937930)

Date	Temp (C)	DO (mg/L)	DO < 6.5	Total Phosphorus (mg/L)	Total Phosphorus > 0.05 mg/L?
10/15/03	7.24	10.39	No	0.01	No
08/04/04	11.81	9.23	No	0.01	No
09/15/05	8.34	9.68	No	0.01	No

n = number of samples na = not available SO = Suspected Outlier
FS = Full Support; PS = Partial Support; NS = Non-Support

The dissolved oxygen standard and total phosphorus indicator were not exceeded during the period of study

No flow data were provided for this STORET station.

4.2.3 Pollutant Loads

The annual total phosphorus load to Red Fleet Reservoir was estimated through a statistical analysis of available flow data collected at USGS gage 09261700 and total phosphorus concentration data collected at Big Brush Creek station 4937860. The steps conducted in calculating the annual average load are described in the following sections and include:

1. Compile all available flow and concentration data

2. Synthesize flow information on dates when flows were not measured
3. Apply range of statistical methods to define daily loads
4. Select results of statistical method with lowest uncertainty, and calculate annual load as the sum of daily loads

Compile all available flow and concentration data

Thirty-nine tributary concentration measurements were available, covering the time frame April 28, 1999 to November 7, 2006. Daily flow measurements were available covering the time frame July 24, 1985 to the present.

Synthesize flow information on dates when flows were not measured

The statistical measures available for estimating annual load require daily stream flow measurements. Small data gaps existed in the available flow record, requiring that tributary flows for these data be estimated. Because the data gaps were of short duration (generally consisting of weekends and holidays), linear interpolation between the nearest available dates of flow measurement was used to synthesize flows for the days when measurements were not available.

Apply range of statistical methods to define daily loads

The third step in estimating annual phosphorus loads consisted of applying a range of candidate statistical methods designed to estimate loads from continuous flow and discrete concentration data. The three methods applied were:

- Minimum variance unbiased estimator (MVUE) regression
- Beale's ratio estimator
- Aggregate method

Daily phosphorus loads were generated using each of the above methods for the entire period of flow record.

Select results of statistical method with lowest uncertainty

An evaluation was made regarding which of the above three statistical techniques for load estimation was most appropriate for Red Fleet Reservoir. Beale's ratio estimator had the lowest standard error of its estimate, and was selected as the most appropriate approach. The best estimate of the annual phosphorus loading rate for Red Fleet Reservoir is 1,489 kg/yr (Table 33).

Table 33
Annual Average Phosphorus Load Using the Beales Ratio Estimator

Method	Beale's ratio estimator
Annual TP Load (kg/yr)	1,489

4.2.4 Source Assessment

There are no point sources of pollution in Red Fleet Reservoir's watershed, all existing pollutants originate from nonpoint sources. Simplot Phosphate, a large mining operation along Big Brush Creek west of US-191 has a groundwater permit for its tailings pond but there are no surface water discharges into Big Brush Creek. The mine practices careful revegetation of disturbed areas and has a large settling pond to remove solids from runoff (Judd, 1997).

Current nonpoint sources in the watershed in order of significance include in-lake sources, upland erosion, and recreational sources. An adaptive management approach was chosen as the most appropriate means to address these sources due to the uncertainty associated with their diffuse and highly variable nature and the assurance of future data collection to measure progress towards the identified load reduction goals.

Source Identification

There are several potential mechanisms by which phosphorus can enter the water column from sources within and external to Red Fleet Reservoir. The following sections describe these sources in more detail and provide an approximation of the relative magnitude of the loading from each source to Red Fleet Reservoir.

Internal Loading

Bottom sediments have long been acknowledged as a source of phosphorus to the overlying waters of lakes and reservoirs (Chapra, 1997). This is particularly true in lakes and reservoirs in which anaerobic conditions occur in the hypolimnion. Under anaerobic conditions, phosphorus in the sediments can be converted into soluble forms that are more available for algae growth. The soluble phosphorus can then be released into the overlying water column. When mixing occurs during spring and fall turnover, the soluble phosphorus can be carried into the upper water column where it is utilized by algae for growth.

The process by which the bottom sediments interact with the overlying water column is controlled by the length and severity of anoxia in the hypolimnion, the chemical constituents and phosphorus content of the sediments and the surface area of anoxic bottom sediments. Red Fleet Reservoir experiences short periods of anoxia in the hypolimnion during the late summer months and increasing phosphorus concentrations near the lake bottom as shown by water column profile data so internal loading is characterized as a moderate source of phosphorus into Red Fleet Reservoir.

Upland Erosion

Red Fleet Reservoir is surrounded by sparsely vegetated pinyon-juniper woodlands that characteristically have little effective ground cover to prevent soil erosion. During intense summertime convective storms there is the potential for sheetflow to carry sediment into the Reservoir. However, much of the shoreline is actually non-erodable bedrock, particularly near the inlet of Big Brush Creek into the Reservoir so overall upland erosion is not considered to be a significant source of pollutant loading.

Recreational Sources

Human caused recreational sources include litter and human waste. Red Fleet Reservoir features a well maintained State Park with trash bins, restroom facilities, fish cleaning stations and improved camp sites. Based on the availability of recreational facilities and their maintenance recreational sources of pollutant loading are not considered significant.

4.2.5 Linkage Analysis

The BATHTUB water quality model was used to define the relationship between external phosphorus loads and resulting concentrations of total phosphorus, chlorophyll a, and dissolved oxygen in Red Fleet Reservoir. The model application is described in the following sections, including information on:

- Model selection
- Model inputs
- Model calibration
- Model application for TMDL development

Model Selection

The BATHTUB model (Walker, 1985) was selected to address phosphorus/dissolved oxygen impairments in Red Fleet Reservoir. This model was selected because it does not have extensive data requirements (and can therefore be applied with existing data), yet still provides the capability for calibration to observed lake data. BATHTUB has been used previously for several reservoir TMDLs nationwide, and has been cited as an effective tool for lake and reservoir water quality assessment and management, particularly where data are limited (Ernst et al., 1994).

The model was used to predict the relationship between phosphorus load and resulting in-lake phosphorus and chlorophyll a concentrations, as well metalimnetic oxygen demand.

Model Inputs

This section provides an overview of the model inputs required for BATHTUB application, and how they were derived. The following categories of inputs are required for BATHTUB:

- Model Options
- Global Variables
- Reservoir Segmentation
- Tributary Loads

Model Options

BATHTUB provides a multitude of what are termed "model options". These options allow the modeler to tailor the modeling approach to address only those constituents of concern, using model equations that best reflect site-specific conditions. The BATHTUB model options selected for Red Fleet Reservoir are shown in Table 34, with the rationale for these options discussed below. In general, the default model options specified by BATHTUB were selected unless site-specific information indicated that a different approach was more applicable.

No conservative substance was simulated, so this option was not needed. The second order option was selected for phosphorus as this is the default approach in BATHTUB. Total nitrogen was not simulated, because the reservoir experiences periods of phosphorus limitation and because phosphorus is more easily controlled from a management perspective than nitrogen sources. Chlorophyll a was simulated using the default BATHTUB approach. Water transparency were not simulated. The Fischer numeric dispersion model was selected, which is the default approach in BATHTUB. Phosphorus calibrations were based on lake concentrations. The use of availability factors was not required, and estimated concentrations were used to generate mass balance tables.

Table 34
BATHTUB Model Options for Red Fleet Reservoir

MODEL	**MODEL OPTION**
Conservative substance	Not computed
Total phosphorus	2nd order
Total nitrogen	Not computed
Chlorophyll-a	Phosphorus, Light, T
Transparency	Not computed
Longitudinal dispersion	Fischer-numeric
Phosphorus calibration	Concentrations
Nitrogen calibration	None

Error analysis	Not computed
Availability factors	Ignored
Mass-balance tables	Use estimated concentrations

Global Variables

The global variables required by BATHTUB consist of:

- The averaging period for the analysis
- Precipitation, evaporation, and change in lake levels
- Atmospheric phosphorus loads

BATHTUB is a steady state model, whose predictions represent concentrations averaged over a period of time. A key decision in the application of BATHTUB is the selection of the length of time over which inputs and outputs should be modeled. The length of the appropriate averaging period for BATHTUB application depends upon the nutrient residence time, which is the average length of time that phosphorus spends in the water column before settling or flushing out of the lake. Guidance for the BATHTUB model recommends that the averaging period used for the analysis be at least twice as large as the nutrient residence time for the lake of interest. The nutrient residence time for Red Fleet Reservoir was approximately five months, so an annual averaging period was used.

Precipitation inputs for the lakes were taken from the observed precipitation data and scaled to the appropriate simulation period. This resulted in a precipitation value of 14 inches for Red Fleet Reservoir. The change in storage during the modeling period was based upon observation of water level during the year. The values selected for precipitation and change in lake levels have little influence on model predictions. Atmospheric phosphorus loads were specified using default values provided by BATHTUB.

Reservoir Segmentation

BATHTUB provides the capability to divide the reservoir under study into a number of individual segments, allowing prediction of the change in phosphorus concentrations over the length of the reservoir. BATHTUB requires that a range of inputs be specified for each segment.

These include segment surface area, length, total water depth, depth of thermocline and mixed layer; and observed water quality data to support model calibration. A single-segment approach was selected for Red Fleet Reservoir, as the majority of water quality data were collected at a single station. A complete listing of all segment-specific inputs is provided in Attachment xx (to be provided).

Tributary Loads

BATHTUB requires information describing tributary flow and nutrient concentrations into each reservoir segment. The approach used to estimate flows and loads was discussed previously.

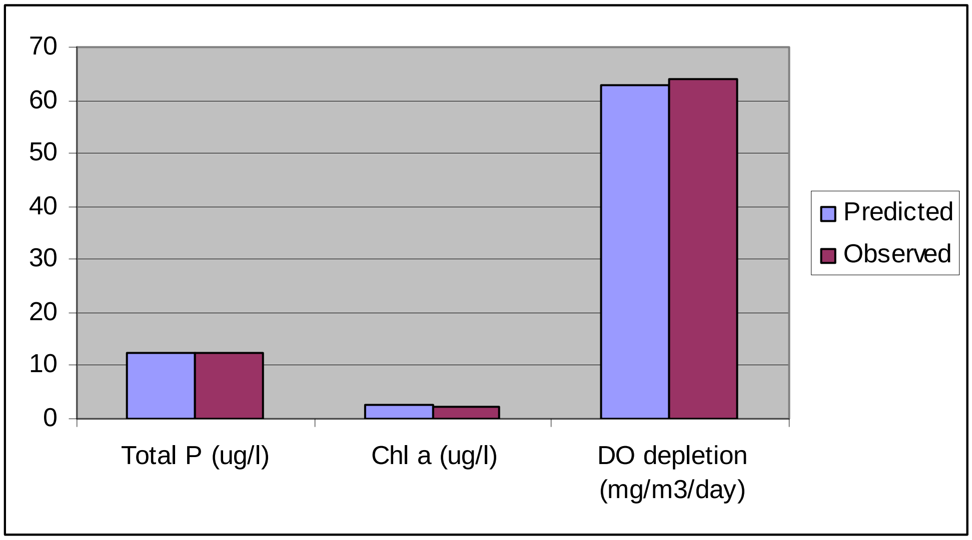
BATHTUB Calibration

BATHTUB model calibration consists of:

1. Applying the model with all inputs specified as above
2. Comparing model results to observed phosphorus data
3. Adjusting model coefficients to provide the best comparison between model predictions and observed phosphorus data.

The BATHTUB model was applied with the model inputs as specified above. The model calibration period represented an average condition across all years for which data were available. BATHTUB was first calibrated to match the observed reservoir total phosphorus concentrations. The resulting predicted lake average total phosphorus concentration was 0.017 mg/L, compared to an observed average of 0.013 mg/L. A calibration adjustment factor of 0.76 was used to bring the predicted phosphorus concentration in alignment with the observed data. BATHTUB results were then compared to observed chlorophyll a. The predicted chlorophyll a concentration was 0.0025 mg/L, compared to an observed average of 0.0021 mg/L. Finally, the predicted metalimnetic oxygen depletion rate was compared to the observed. The initial predicted oxygen depletion rate was 46 mg O_2/m3/day, compared to an observed average of 64 mg O^2/m^3/day. The oxygen depletion rate was adjusted via the calibration process to a value of 63 mg O_2/m^3. A comparison of final model predictions vs. observed data is shown in Figure 13. This comparison represents an acceptable model calibration.

Figure 13
BATHTUB Model Calibration Results for Red Fleet Reservoir



<u>Model application for TMDL development</u>

The calibrated BATHTUB model was applied to determine the level of phosphorus loading reduction required to maintain compliance with the dissolved oxygen target (specified as a dissolved oxygen concentration above 4 mg/L at the 50% depth in the water column). The most critical period for oxygen assessment will occur just prior to fall turnover, when the lake has been stratified for the maximum possible time. The BATHTUB output, which is specified as an oxygen depletion rate, can be converted into a dissolved oxygen concentration suitable for comparison to the target, via the following equation:

DO at turnover =
DO at onset of stratification –
(DO depletion rate) x number of days of stratification (1)

Equation 1 can be rearranged to solve for a target oxygen depletion rate, i.e. one that will lead to compliance with the dissolved oxygen target of 4.0 mg/L just at the onset of stratification:

Target DO depletion rate = (DO at turnover – 4.0)/number of days of stratification (2)

The available data were examined and the average dissolved oxygen at the onset of stratification was calculated as 6.8 mg/L while the average duration of stratification was calculated at 106 days. Entering these values into Equation 2 results in a target DO depletion rate of 0.026 mg/L/day (26 mg O_2/m^3/day).

The BATHTUB model was then run to determine the maximum allowable phosphorus load that would maintain compliance with the target DO depletion rate. This target loading was 150 kg/yr, corresponding to a 90% reduction in existing loads.

This level of loading reduction is expected to unattainable in the Red Fleet watershed.

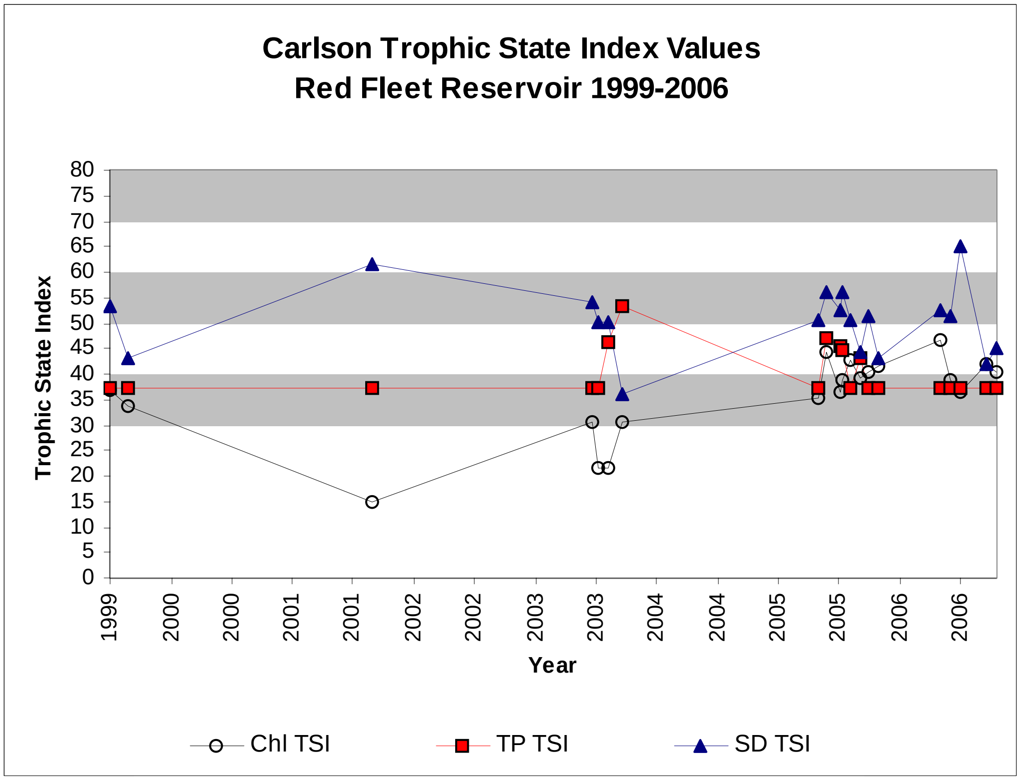
4.2.6 Trophic State Assessment

Trophic indices for Red Fleet reservoir based on chlorophyll *a* concentrations from 1999 to 2006, ranged from 15 to 41 with an average of 31 demonstrating that it is an oligotrophic system having clear water with limited periods of hypolimnetic anoxia (Table 35). In contrast, trophic indices based on Secchi Depth concentrations (range from 48 to 62 with an average of 59) were much greater classifying the reservoir as eutrophic with an anoxic hypolimnion and decreasing transparency. Total Phosphorous (range from 32 to 44 with an average of 39) indices place the reservoir at the mesotrophic level with moderately clear water and hypolimnetic anoxia in the summer. There is no discernable trend whether the system is degrading or improving during the study period (Figure 14).

Table 35
Red Fleet Reservoir Trophic State Index

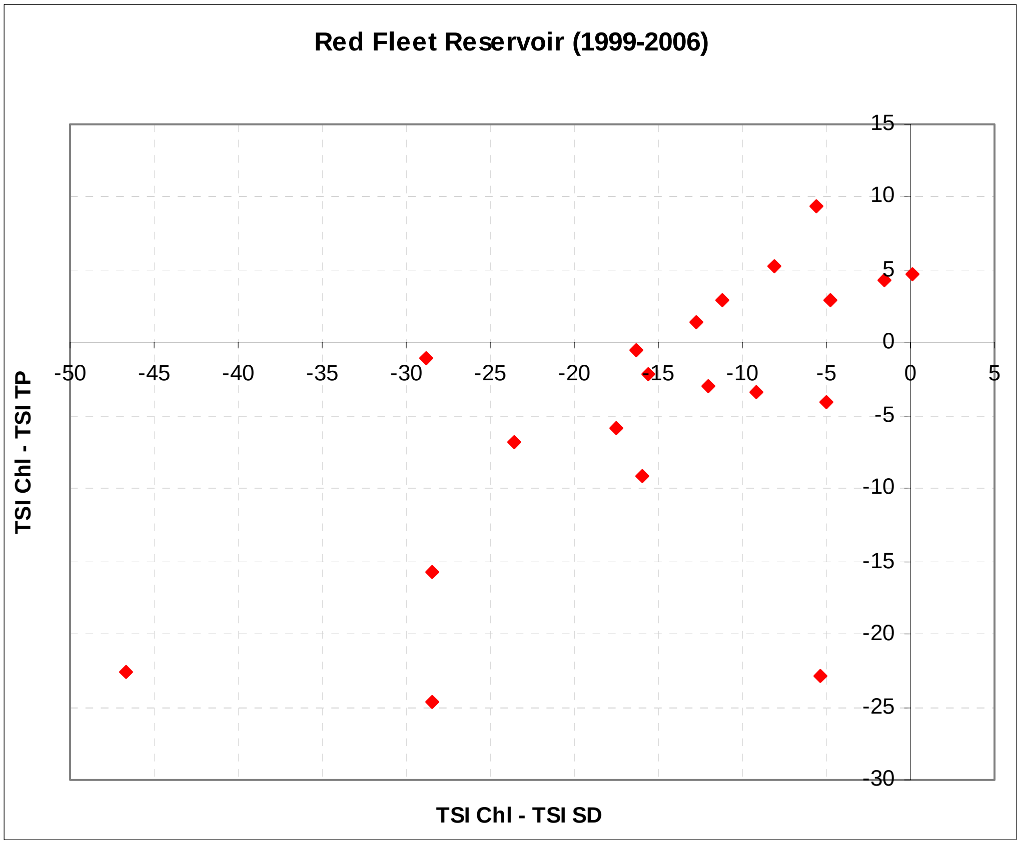
Year	TSI (CHL)	TSI (SD)	TSI (TP)
1999	35	48	37
2001	15	62	37
2003	26	48	44
2005	40	51	41
2006	41	51	37
Average	31	59	39

Figure 14
Red Fleet Reservoir Trophic State Index



Since the deviation of all three trophic indices (chl a, TP and SD) placed the reservoir at the eutrophic, mesotrophic and oligotrophic levels, the relationship between the TSI variables was further investigated as suggested by Carlson (Carlson 1992). TSI(CHL)-TSI(TP) versus TSI(CHL-TSI(SD) was plotted to further examine systematic deviations (Figure 15).

Figure 15
Red Fleet Reservoir Trophic State Index Deviations



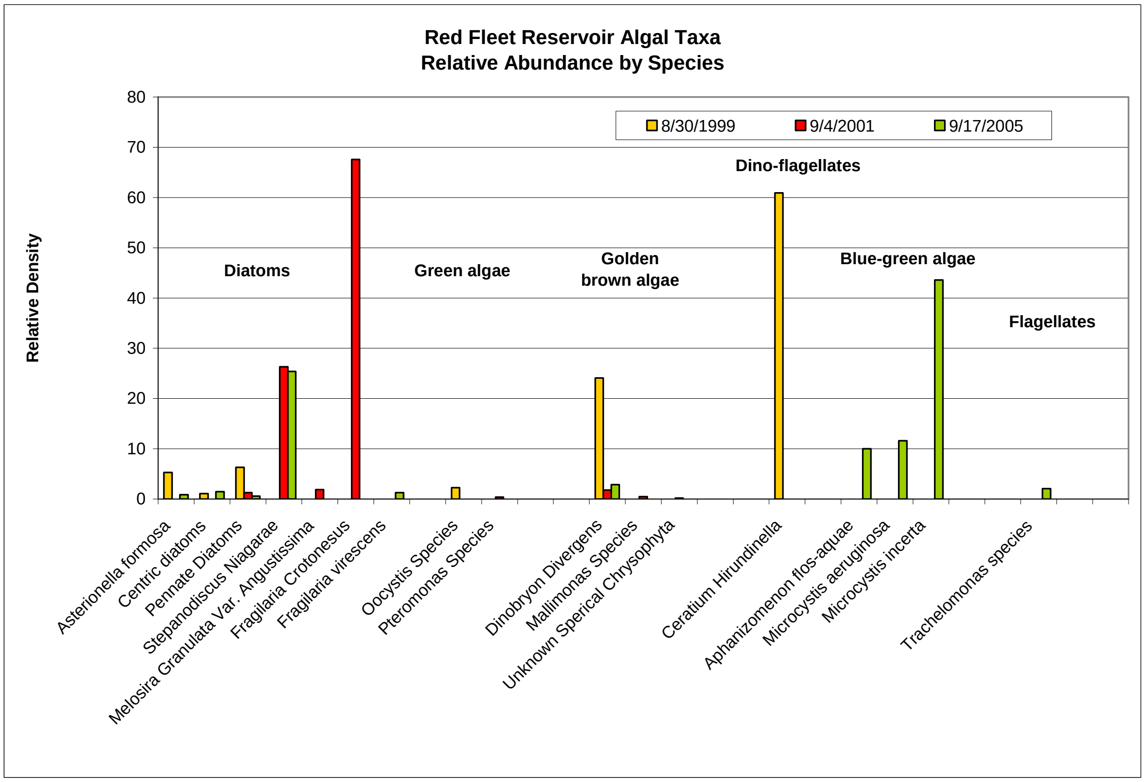
All of the plotted points fall within the negative x coordinate system. Carlson suggests that this occurs when non-algal factors dominate such as color, turbidity or very small particles predominate. As points increase above the zero line, this suggests increasing phosphorus limitation (Carlson, 1992). For Red Fleet Reservoir, the average N:P ratio over the study period was calculated as 9.3 with 43% of the samples greater than 7.2 (the theoretical division between nitrogen and phosphorous limitation). This indicates that phosphorus is the limiting nutrient much of the time, and perhaps most of the time depending on the extent to which the "pseudo" N:P ratio underestimates the true N:P ratio.

4.2.7 Phytoplankton Assessment

Phytoplankton data were collected from the euphotic zone in 1999, 2001 and 2005 (Figure 16). The 2001 sample indicates the phytoplankton community was dominated by the dinophyta *Ceratium hirundinella* (61%) with the remainder of the sample consisting of golden brown algae and diatoms. In 2001, the sample was dominated by the diatoms specifically (67%) and *Stephanodiscus niagarae* (26%). Blue green algae, an algal indicator of eutrophy, appears in

2005 totaling 65 % of the sample primarily *Microcystis incerta* (44%). Though these 3 samples reflect the biological condition at a point in time they do not address seasonal phytoplankton succession nor can definitively address phytoplankton species composition changes in relation to trophic status over time.

Figure 16
Red Fleet Reservoir Algal Taxa



4.2.8 Sediment Oxygen Demand

The rate of sediment oxygen demand (SOD) occurring in each reservoir can be estimated from historically observed data defining the decrease in hypolimnetic dissolved oxygen over the course of a summer (i.e. DO depletion rates).

SOD (g/m2/day) = [Observed DO depletion rate – DO depletion due to water column] x Water Depth.

The above equation is based on the fact that oxygen depletion in the hypolimnion is caused by two separate sources: 1) oxygen depletion due to water column BOD and algal respiration, and 2) oxygen depletion due to SOD. The observed oxygen depletion rate reflects the combined effect of both sources. The SOD component can therefore be calculated by subtracting the water column component from the observed total. Chapra (1997) indicates that it can be assumed that SOD is the primary cause of hypolimnetic oxygen depletion, such that the water column contribution can be ignored in the equation above. SOD calculations for Red Fleet Reservoir are provided in Table 36.

Table 36
Red Fleet Reservoir SOD Calculations

Observed DO Depletion rate ($g/m^3/day$)	Hypolimnetic Depth (m)	Estimated SOD ($g/m^2/day$)
0.064	7	0.45

While there are no definitive guidelines, an estimated SOD of 0.45 $g/m^2/day$ would be considered at the low range for mesotrophic lakes.

4.2.9 Seasonality

These TMDL calculations were conducted with an explicit consideration of seasonal variation. The BATHTUB model is designed to evaluate seasonal to annual loads. Annual loads were calculated by summing the individual daily loads over the course of a year, and fully capturing seasonal variability. The annual loading analysis that was used is appropriate due to the long response time between phosphorus loading and biotic response.

4.3 Steinaker Reservoir

4.3.1 Stations and Data

DWQ identified five STORET stations near Steinaker Reservoir for this TMDL water quality study. These stations and the years of available data for the period of study are listed in Table 37.

Table 37
STORET Stations Containing Water Quality Data for the Period of Study

STORET	Type	Description	Sample Years
4937520	River/Stream	STEINAKER Feeder Canal at Taylor Mountain Road above Reservoir*	1999 2001 2003 2005 2006
4937550	Lake	STEINAKER RESERVOIR ABOVE DAM 01	2001 2003 2005 2006
4937560	Lake	STEINAKER RESERVOIR SOUTH ARM 03	2001
4937570	Lake	STEINAKER RESERVOIR NORTH ARM 02	1999
4937710	River/Stream	Dry-Fork Creek Above Confluence with Ashley Creek	1996 2000 2001 2005 2006

*DWQ changed the name of this station in May 2007. The previous name was “STEINAKER DITCH”.

Three of the STORET stations listed in Table 37 have been sampled with sufficient frequency for the Steinaker Reservoir TMDL water quality study. These three STORET stations include: # 4937510 (STEINAKER Feeder Canal at Taylor Mountain Road above Reservoir), #4937550 (STEINAKER REServoir ABove DAM 01), and #4937710 (Dry-Fork Creek Above Confluence with Ashley Ck).

The raw data and statistical summaries of available data collected at the three STORET stations described above for the period of study are provided in **Error! Reference source not found.**. For each station, the data are tabulated from the raw output and followed by descriptive statistics. The statistics list the number, minimum, maximum, mean, standard deviation, and the mean plus 2 standard deviations (for outlier analysis). Laboratory detection limits for each parameter were provided by DWQ. Where results were below the laboratory detection limit, one-half the detection limit was entered for statistical analyses. It is important to note that although water quality exceedences are displayed in the table, it is not intended to be used in comparison to 303(d) listing criteria.

Outlier Analysis and Treatment of Results Below Laboratory Detection Limits

Results that fall outside the control limits of plus two standard deviations from the mean were judged to be suspected outliers and removed from further statistical analysis.

For reservoir sampling, DWQ collects depth profile data using a data that records temperature, pH, specific conductivity, and dissolved oxygen at approximately one-meter intervals through the water column. Combined with depth profile sampling, grab samples are collected at the water surface, one meter above the thermocline, one meter below the thermocline, and one meter from the bottom of the reservoir.

Parameters of interest to this TMDL water quality study and the number of reservoir samples collected during the period of study are listed in Table 38.

Table 38
Parameters and Number of Results for the Steinaker Reservoir STORET Station for the Period of Study

Parameter	4937550 - Steinaker Reservoir Above Dam
Datalogger Profiles	Year – No. of Profiles: 2001 - 2 2003 - 4 2005 - 3 2006 - 4
Number of Results (excluding outliers):	
Depth	337
Water Temperature	337
Dissolved Oxygen	337
Dissolved Oxygen Saturation	321
Total Phosphorus	37
Chlorophyll-a	15
Depth Secchi Disk	15
Nitrogen as Nitrate + Nitrite	53
Nitrogen as Ammonia	53

Additional data are available for the two tributary stations above Steinaker Reservoir: STEINAKER Feeder Canal at Taylor Mountain Road above Reservoir (STORET 4937520) and Dry-Fork Creek Above Confluence with Ashley Ck (STORET 4937710). For the period of study, the years of available data from these stations are listed in Table 37. Parameters of interest to this TMDL water quality study and the number of tributary samples collected at these stations during the period of study are listed in Table 39.

Table 39
Parameters and Number of Results for Steinaker Reservoir Tributary STORET Stations for the Period of Study

Parameter	4937520 STEINAKER Feeder Canal at Taylor Mtn Rd ab Reservoir	4937710 Dry-Fk Ck Ab Cnfl / Ashley Ck
Number of Results (excluding outliers):		
Water Temperature	8	18
Dissolved Oxygen	8	17
Total Phosphorus	9	15
Dissolved Phosphorus	11	12
Nitrogen as Nitrate + Nitrite	10	15
Nitrogen as Ammonia	11	13
Total Suspended Solids	10	7
Turbidity	0	16

4.3.2 Summary of Impairment

STORET 4937550 – Steinaker Reservoir Above Dam

STORET data for station 4937550 (Steinaker Reservoir Above Dam), includes data from 13 depth profiles in addition to other chemistry results for a total of 17 sampling events over the study period. The parameters of interest and associated statistics for evaluation of the water quality of Steinaker Reservoir as related to the impaired designated beneficial use (cold water fishery), due to low dissolved oxygen, are listed in **Error! Reference source not found.** and summarized in Table 40.

Table 40
STORET Summary for Steinaker Reservoir Above Dam (4937550)

	Dissolved Oxygen	Total Phosphorus

Date	Depth (m)	n	Average Temp (C)	Average (mg/L)	n	% > 4 mg/L	Support Status	Average (mg/L)	n	Average > 0.025 mg/L?
07/22/97	27.4	4	25.0	5.68	4	100%	FS		0	
09/16/97	25.0	4	13.9	4.65	4	50%	PS		0	
07/06/99	28.0	4	15.5	6.85	4	100%	FS	0.013	4	No
08/31/99	25.3	4	16.0	3.08	4	25%	PS	0.015	4	No
06/26/01	16.9	18	16.0	6.94	18	100%	FS	0.010	3	No
09/04/01	21.4	23	16.6	3.60	23	48%	PS		0	
06/25/03	26.5	24	12.5	5.64	24	100%	FS	0.010	3	No
07/16/03	25.9	27	14.2	4.32	27	33%	PS	0.010	3	No
08/13/03	22.4	25	15.9	3.04	25	28%	PS	0.029	2	Yes
09/25/03	16.0	17	13.8	4.71	17	59%	FS	0.036	3	Yes
07/20/05	25.2	27	15.6	5.86	27	100%	FS	0.014	4	No
08/04/05	31.0	32	14.6	3.20	32	22%	NS		0	
09/06/05	31.5	33	14.7	2.99	33	30%	PS	0.015	3	No
06/14/06	31.6	31	12.7	6.59	31	97%	FS	0.010	4	No
07/11/06	28.7	30	14.3	5.34	30	90%	FS	0.014	4	No
08/15/06	19.2	21	17.6	3.97	21	38%	PS	0.021	4	No
10/04/06	11.6	13	15.8	7.14	13	100%	FS	0.010	4	No

n = number of samples na = not available
FS = Full Support; PS = Partial Support; NS = Non-Support

Based on the water quality criteria for dissolved oxygen for reservoirs designated beneficial use 3A, the reservoir showed a partial support status during seven sampling events (September 1997, August 1999, September 2001, July 2003, August 2003, September 2005, and August 2006), and non-support status during one sampling event (August 2005). The average total phosphorous in the water column exceeded the total phosphorus indicator value of 0.025 mg/L during two sampling events (0.029 mg/L in August 2003 and 0.036 mg/L in September 2003).

STORET 4937520 – Steinaker Feeder Canal at Taylor Mountain Road Above Reservoir

All applicable STORET data for Station 4937520 are provided in **Error! Reference source not found.** and summarized in Table 41.

Table 41
STORET Summary for Steinaker Feeder Canal at Taylor Mountain Road Above Reservoir (4937520)

Date	Temp (C)	DO (mg/L)	DO < 6.5	Total Phosphorus (mg/L)	Total Phosphorus > 0.05 mg/L?
08/31/99	20.8	6.70	No	0.035	No
06/26/01	na	na		0.010	No
07/16/03	27.7	6.11	Yes	0.010	No
09/25/03	7.2	9.42	No	0.074 SO	
06/23/05	na	na		0.025	No
08/04/05	20.2	5.63	Yes	0.010	No
08/02/06	15.2	9.36	No	0.010	No
08/15/06	22.7	9.89	No	0.010	No
10/03/06	16.0	8.14	No	0.010	No
11/07/06	9.4	8.64	No	0.010	No

n = number of samples na = not available SO = Suspected Outlier
FS = Full Support; PS = Partial Support; NS = Non-Support

The dissolved oxygen standard was less than 6.5 mg/L twice during the period of study measured as 6.11 mg/L on July 16, 2003 and 5.63 mg/L on August 4, 2005. The total phosphorus indicator of 0.05 mg/L was not exceeded.

No flow data were provided for this STORET station.

STORET 4937710 – Dry Fork Creek Above Confluence with Ashley Creek

All applicable STORET data for Station 4937710 are provided in **Error! Reference source not found.** and summarized in Table 42.

Table 42
STORET Summary for Dry Fork Creek Above Confluence with Ashley Creek (4937710)

Date	Temp (C)	DO (mg/L)	DO < 6.5	Total Phosphorus (mg/L)	Total Phosphorus > 0.05 mg/L?
06/11/96	14.22	7.93	No	0.010	No
10/19/00	7.89	9.90	No	0.010	No
12/14/00	0.19	9.41	No	0.010	No
01/10/01	0.46	11.24	No	3.708 SO	
02/07/01	0.26	10.48	No	0.010	No
04/04/01	12.19	7.23	No	0.010	No
04/24/01	17.08	8.73	No	0.010	No
05/09/01	13.18	8.37	No	0.034	No
05/23/01	11.60	8.91	No	0.020	No
06/06/01	14.62	8.06	No	0.023	No
07/20/05	11.71	9.53	No	0.010	No
08/16/05	16.91	8.25	No	0.010	No
09/13/05	16.29	8.13	No	0.010	No
10/11/05	11.74	8.96	No	0.010	No
11/08/05	8.57	9.15	No	0.010	No
12/13/05	0.28	11.96	No	0.010	No
01/17/06	-0.19	12.78 SO		na	
02/14/06	0.13	11.21	No	na	

n = number of samples   na = not available   SO = Suspected Outlier
FS = Full Support; PS = Partial Support; NS = Non-Support

The dissolved oxygen standard and total phosphorus indicator were not exceeded during the period of study. No flow data were provided for this STORET station.

4.3.3 Pollutant Loads

Annual Load

The annual total phosphorus load to Steinaker Reservoir was estimated through a statistical analysis of available flow data collected by the Uinta Water Conservancy District at the Steinaker Feeder Canal gage and total phosphorus concentration data collected at Steinaker Feeder Canal at Taylor Mountain Road, station number 4937520. The steps conducted in calculating the annual average load were:

1. Compile all available flow and concentration data
2. Synthesize flow information on dates when flows were not measured
3. Apply range of statistical methods to define daily loads

4. Select results of statistical method with lowest uncertainty and calculate annual load as the sum of daily loads

<u>Compile all available flow and concentration data</u>

Ten tributary concentration measurements were available, covering the time frame August 31, 1999 to November 7, 2006. Daily flow measurements were available covering the time frame October 1, 1996 to January 19, 2007.

<u>Synthesize flow information on dates when flows were not measured</u>

The statistical measures available for estimating annual load require daily stream flow measurements. Small data gaps existed in the available flow record, requiring that tributary flows for these data be estimated. Because the data gaps were of short duration (generally consisting of weekends and holidays), linear interpolation between the nearest available dates of flow measurement was used to synthesize flows for the days when measurements were not available.

<u>Apply range of statistical methods to define daily loads</u>

The third step in estimating annual phosphorus loads consisted of applying a range of candidate statistical methods designed to estimate loads from continuous flow and discrete concentration data. The three methods applied were:

- Minimum variance unbiased estimator (MVUE) regression
- Beale's ratio estimator
- Aggregate method

Daily phosphorus loads were generated using each of the above methods for the entire period of flow record.

<u>Select results of statistical method with lowest uncertainty</u>

An evaluation was made regarding which of the above three statistical techniques for load estimation was most appropriate for Steinaker Reservoir. Beale's ratio estimator had the lowest standard error of its estimate, and was selected as the most appropriate approach. The best estimate of the annual phosphorus loading rate for Steinaker Reservoir is 777 kg/yr (Table 43).

Table 43
Annual Average Phosphorus Load Using the Beales Ratio Estimator

Method	Beale's ratio estimator
Annual TP Load (kg/yr)	777

4.3.4 Source Assessment

There are no point sources of pollution in Steinaker Reservoir's watershed, all existing pollutants originate from nonpoint sources. External nonpoint pollution sources reported for Steinaker Reservoir by Judd (1997) include sedimentation and nutrient loading from grazing in the upper watershed, nutrients and sediments from mine sites that have not been reclaimed; sedimentation and increased runoff from logging activities; and wastes and litter from recreation.

Current nonpoint sources in the watershed in order of significance include in-lake sources, upland erosion, and recreational sources. An adaptive management approach was chosen as the most appropriate means to address these sources due to the uncertainty associated with their diffuse and highly variable nature and the assurance of future data collection to measure progress towards the identified load reduction goals.

Source Identification

There are several potential mechanisms by which phosphorus can enter the water column from sources within and external to Steinaker Reservoir. The following sections describe these sources in more detail and provide an approximation of the relative magnitude of the loading from each source to Steinaker Reservoir.

Internal Loading

Bottom sediments have long been acknowledged as a source of phosphorus to the overlying waters of lakes and reservoirs (Chapra, 1997). This is particularly true in lakes and reservoirs in which anaerobic conditions occur in the hypolimnion. Under anaerobic conditions, phosphorus in the sediments can be converted into soluble forms that are more available for algae growth. The soluble phosphorus can then be released into the overlying water column. When mixing occurs during spring and fall turnover, the soluble phosphorus can be carried into the upper water column where it is utilized by algae for growth.

The process by which the bottom sediments interact with the overlying water column is controlled by the length and severity of anoxia in the hypolimnion, the chemical constituents and phosphorus content of the sediments and the surface area of anoxic bottom sediments. Steinaker Reservoir experiences short periods of anoxia in the hypolimnion during the late summer months and increasing phosphorus concentrations near the lake bottom as shown by water column profile data so internal loading is characterized as a moderate source of phosphorus into Steinaker Reservoir.

Upland Erosion

Steinaker Reservoir is surrounded by sparsely vegetated pinyon-juniper woodlands that characteristically have little effective ground cover to prevent soil erosion. During intense summertime convective storms there is the potential for sheetflow to carry sediment into the Reservoir. Another more significant source of eroded sediments is from the Dry Fork drainage that flows into Ashley Creek above the Fort Thornburgh diversion. In May 1997, the Mosby canal, located on a bench above Dry Fork, breached and cut two huge ravines on the east side of Mosby Mountain. The eroded sediment temporarily dammed the creek and after breaching sent a slurry of rock and sediment into the Dry fork Drainage. The canal failure resulted in an estimated 1.5 million cubic yards of sediment and debris being washed into the Dry Fork Creek (DWR, 2003). During spring runoff and late summer rainstorms sediment from this event is still being transported to the reservoir.

Recreational Sources

Human caused recreational sources include litter and human waste. Steinaker Reservoir features a well maintained State Park with trash bins, restroom facilities, fish cleaning stations and improved camp sites. Based on the availability of recreational facilities and their maintenance recreational sources of pollutant loading are not considered significant.

4.3.5 Linkage Analysis

Water Quality Modeling

The BATHTUB water quality model was used to define the relationship between external phosphorus loads and resulting concentrations of total phosphorus, chlorophyll a, and dissolved oxygen in Steinaker Reservoir. The model application is described in the following sections, including information on:

- Model selection
- Model inputs
- Model calibration
- Model application for TMDL development

Model Selection

The BATHTUB model (Walker, 1985) was selected to address phosphorus impairments to Steinaker Reservoir. This model was selected because it does not have extensive data requirements (and can therefore be applied with existing data), yet still provides the capability for calibration to observed lake data. BATHTUB has been used previously for several reservoir TMDLs nationwide, and has been cited as an effective tool for lake and reservoir water quality assessment and management, particularly where data are limited (Ernst et al., 1994).

The model was used to predict the relationship between phosphorus load and resulting in-lake phosphorus and chlorophyll a concentrations, as well metalimnetic oxygen demand.

Model Inputs

This section provides an overview of the model inputs required for BATHTUB application, and how they were derived. The following categories of inputs are required for BATHTUB:

- Model Options
- Global Variables
- Reservoir Segmentation
- Tributary Loads

Model Options

BATHTUB provides a multitude of what are termed “model options”. These options allow the modeler to tailor the modeling approach to address only those constituents of concern, using model equations that best reflect site-specific conditions. The BATHTUB model options selected for Steinaker Reservoir are shown in Table 44, with the rationale for these options discussed below. In general, the default model options specified by BATHTUB were selected unless site-specific information indicated that a different approach was more applicable.

No conservative substance was being simulated, so this option was not needed. The second order option was selected for phosphorus as the model option for BATHTUB which is the default approach in BATHTUB. Total nitrogen was not simulated, because the reservoir experiences periods of phosphorus limitation and because phosphorus is more easily controlled from a management than nitrogen sources. Chlorophyll a was simulated using the default BATHTUB approach. Water transparency was not simulated. The Fischer numeric dispersion model was selected, which is the default approach in BATHTUB. Phosphorus calibrations were based on lake concentrations. The use of availability factors was not required, and estimated concentrations were used to generate mass balance tables.

Table 44
BATHTUB Model Options for Steinaker Reservoir

MODEL	MODEL OPTION
Conservative substance	Not computed
Total phosphorus	2^{nd} order
Total nitrogen	Not computed
Chlorophyll-a	Phosphorus, Light, T
Transparency	Not computed
Longitudinal dispersion	Fischer-numeric
Phosphorus calibration	Concentrations
Nitrogen calibration	None
Error analysis	Not computed
Availability factors	Ignored
Mass-balance tables	Use estimated concentrations

Global Variables

The global variables required by BATHTUB consist of:

- The averaging period for the analysis
- Precipitation, evaporation, and change in lake levels
- Atmospheric phosphorus loads

BATHTUB is a steady state model, whose predictions represent concentrations averaged over a period of time. A key decision in the application of BATHTUB is the selection of the length of time over which inputs and outputs should be modeled. The length of the appropriate averaging period for BATHTUB application depends upon the nutrient residence time, which is the average length of time that phosphorus spends in the water column before settling or flushing out of the lake. Guidance for the BATHTUB model recommends that the averaging period used for the analysis be at least twice as large as the nutrient residence time for the lake of interest. The nutrient residence time for Steinaker Reservoir was approximately five months, so an annual averaging period was used.

Precipitation inputs for the lakes were taken from the observed precipitation data, scaled to the appropriate simulation period. This resulted in a precipitation value of 14 inches for Steinaker Reservoir. A zero net change in storage was assumed for the modeling period since a yearly averaging period was assumed. The values selected for precipitation and change in lake levels have little influence on model predictions. Atmospheric phosphorus loads were specified using default values provided by BATHTUB.

Reservoir Segmentation

BATHTUB provides the capability to divide the reservoir under study into a number of individual segments, allowing prediction of the change in phosphorus concentrations over the length of the reservoir. BATHTUB requires that a range of inputs be specified for each segment. These include segment surface area, length, total water depth, depth of thermocline and mixed layer; and observed water quality data to support model calibration. A single-segment approach was selected for Steinaker Reservoir, as the majority of water quality data were collected at a single station.

Tributary Loads

BATHTUB requires information describing tributary flow and nutrient concentrations into each reservoir segment. The approach used to estimate flows and loads was discussed previously.

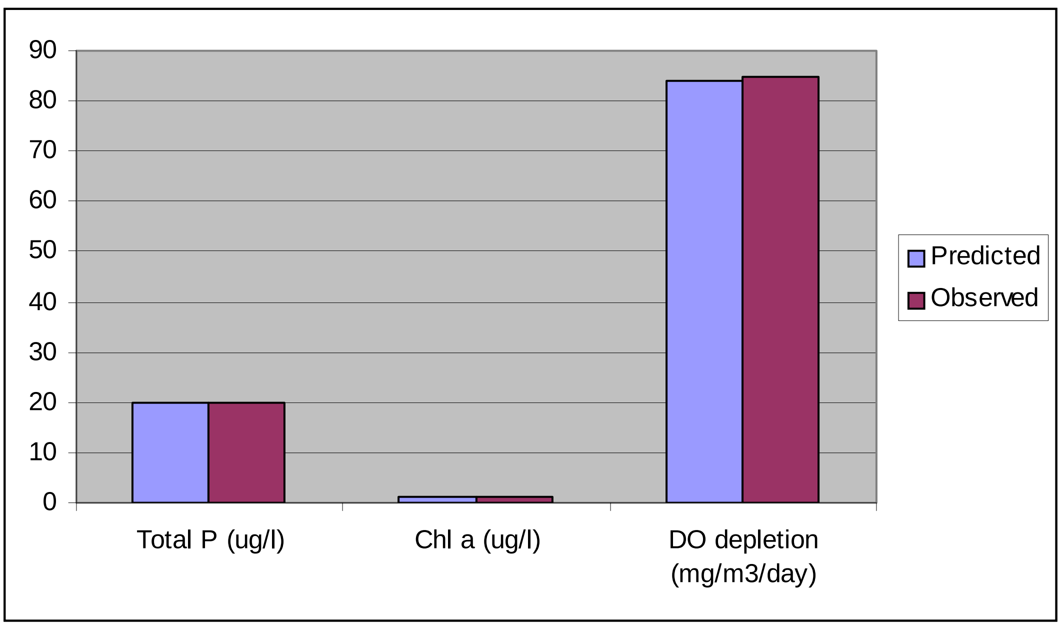
BATHTUB Calibration

BATHTUB model calibration consists of:

1. Applying the model with all inputs specified as above
2. Comparing model results to observed phosphorus data
3. Adjusting model coefficients to provide the best comparison between model predictions and observed phosphorus data.

The BATHTUB model was applied with the model inputs as specified above. The model calibration period represented an average condition across all years for which data were available. BATHTUB was first calibrated to match the observed reservoir total phosphorus concentrations. An internal phosphorus load of 1.1 mg/m2-day (1350 kg/yr) was used to bring the predicted phosphorus concentration in alignment with the observed data. The use of an internal loading can be justified by the observed presence of significant increases in hypolimnetic phosphorus concentrations during summer months, indicating release of phosphorus from bottom sediments. The resulting predicted lake average total phosphorus concentration was 0.0198 mg-P/L, compared to an observed average of 0.0200 mg-P/L. BATHTUB results were then compared to observed chlorophyll a. The predicted chlorophyll a concentration was 0.001 mg/L, compared to an observed average of 0.0011 mg/L. A calibration adjustment factor of 0.25 was used to bring the predicted chlorophyll a concentration in alignment with the observed data. Finally, the predicted metalimnetic oxygen depletion rate was compared to the observed. The initial predicted oxygen depletion rate was 28 mg O_2/m^3/day, compared to an observed average of 85 mg O_2/m^3/day. The oxygen depletion rate was adjusted via the calibration process to a value of 84 mg O_2/m^3. A comparison of final model predictions vs. observed data is shown in Figure 17. This comparison represents an acceptable model calibration.

Figure 17
BATHTUB Model Calibration Results for Steinaker Reservoir



Model application for TMDL development

The calibrated BATHTUB model was applied to determine the level of phosphorus loading reduction was required to maintain compliance with the dissolved oxygen target (specified as a dissolved oxygen concentration above 4 mg/L at the 50% depth in the water column). The most critical period for oxygen assessment will occur just prior to fall turnover, when the lake has been stratified for the maximum possible time. The BATHTUB output, which is specified as an oxygen depletion rate, was converted into a dissolved oxygen concentration suitable for comparison to the target using the same equations described previously for Brough Reservoir, rearranged to solve for a target oxygen depletion rate, i.e. one that will lead to compliance with the dissolved oxygen target of 4.0 mg/L just at the onset of stratification.

The available data were examined and the average dissolved oxygen at the onset of stratification was calculated as 5.8 mg/L while the average duration of stratification was calculated at 77 days. Entering these values into Equation 2 results in a target DO depletion rate of 0.023 mg/L/day (23 mg O_2/m^3/day).

The BATHTUB model was then run to determine the maximum allowable phosphorus load that would maintain compliance with the target DO depletion rate. This target loading was 22 kg/yr, corresponding to a 97% reduction in existing loads.

This level of loading reduction is expected to be unattainable in the Steinaker Reservoir watershed.

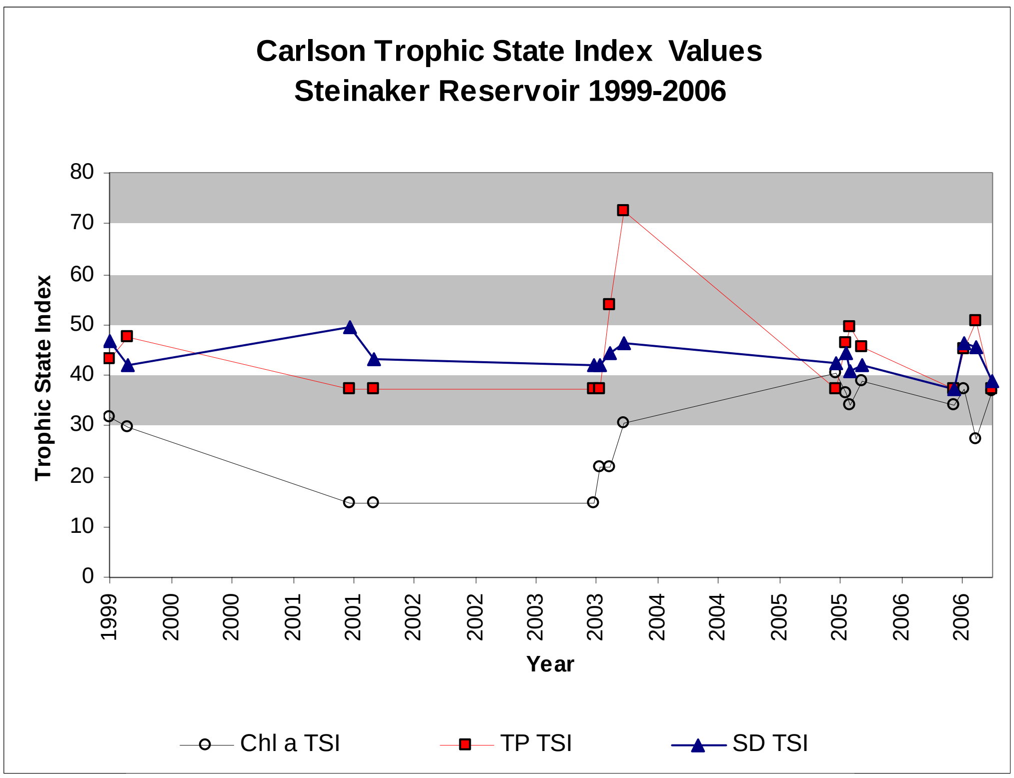
4.3.6 Trophic State Assessment

Trophic indices for Steinaker Reservoir based on chlorophyll *a* concentrations from 1999 to 2006, ranged from 15 to 37 with an average of 28 demonstrating that it is an oligotrophic system having clear water with limited periods of hypolimnetic anoxia (Table 45). In contrast, trophic indices based on Secchi Depth concentrations (range from 42 to 44 with an average of 44) and Total Phosphorous (range from 37 to 50 with an average of 44) were higher indicating the reservoir is mesotrophic with moderately clear water and hypolimnetic anoxia in the summer. While TSI values based on all indicators increased in 2003 (an extreme drought year), there is no discernable trend whether the system is degrading or improving during the study period (Figure 18).

Table 45
Steinaker Reservoir Trophic State Index

Year	TSI (CHL)	TSI (SD)	TSI (TP)
1999	31	44	45
2001	15	46	37
2003	22	44	50
2005	37	42	45
2006	34	42	43
Average	28	44	44

Figure 18
Steinaker Reservoir Trophic State Index



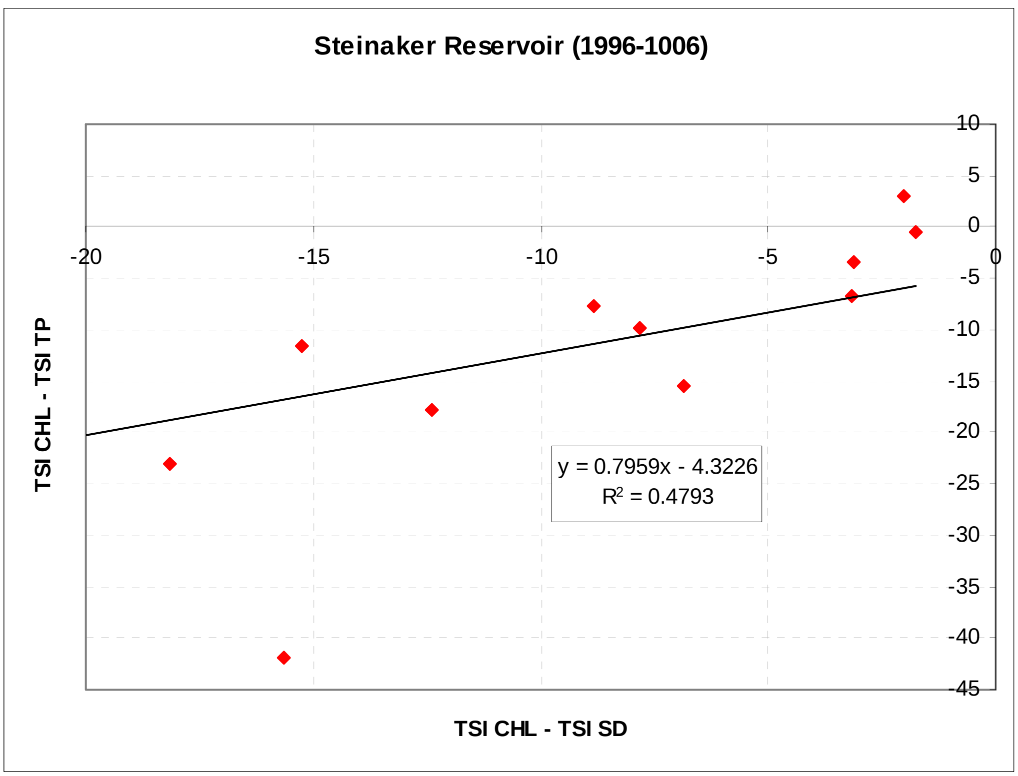
Since the deviation of the Total Phosphorus and Secchi Depth trophic indices from the chlorophyll TSI values placed the reservoir in a higher trophic level, the relationship between the TSI variables was further investigated as suggested by Carlson (Carlson 1992). TSI(CHL)-

TSI(TP) versus TSI(CHL)-TSI(SD) was plotted to further examine systematic deviations (Figure 19).

The majority of plotted points fall within the negative x and y coordinate systems. This quadrant suggests transparency could be attributed to non-algal related turbidity such as color or small particles and something other than phosphorus is limiting algal growth (Carlson, 1992)

Non-algal related turbidity may not be captured in this data. Typically the reservoir is filled until the irrigation season begins in May. Spring flooding and flushing of sediments occurs annually in April and may limit algal growth due to light limitations. In addition, in May 1997, the Mosby canal breached and cut two huge ravines on the east side of Mosby Mountain sending a sediment slurry into the Dry fork Drainage. The canal failure resulted in an estimated1-1/2 million cubic yards of debris being washed into the Dry Fork Creek a tributary to Ashley Creek upstream of Steinaker Reservoir (DWR, 2003). Since then, during spring runoff and late summer rainstorms, sediment from this event is still contributing to the reservoir.

Figure 19
Red Fleet Reservoir Trophic State Index Deviations

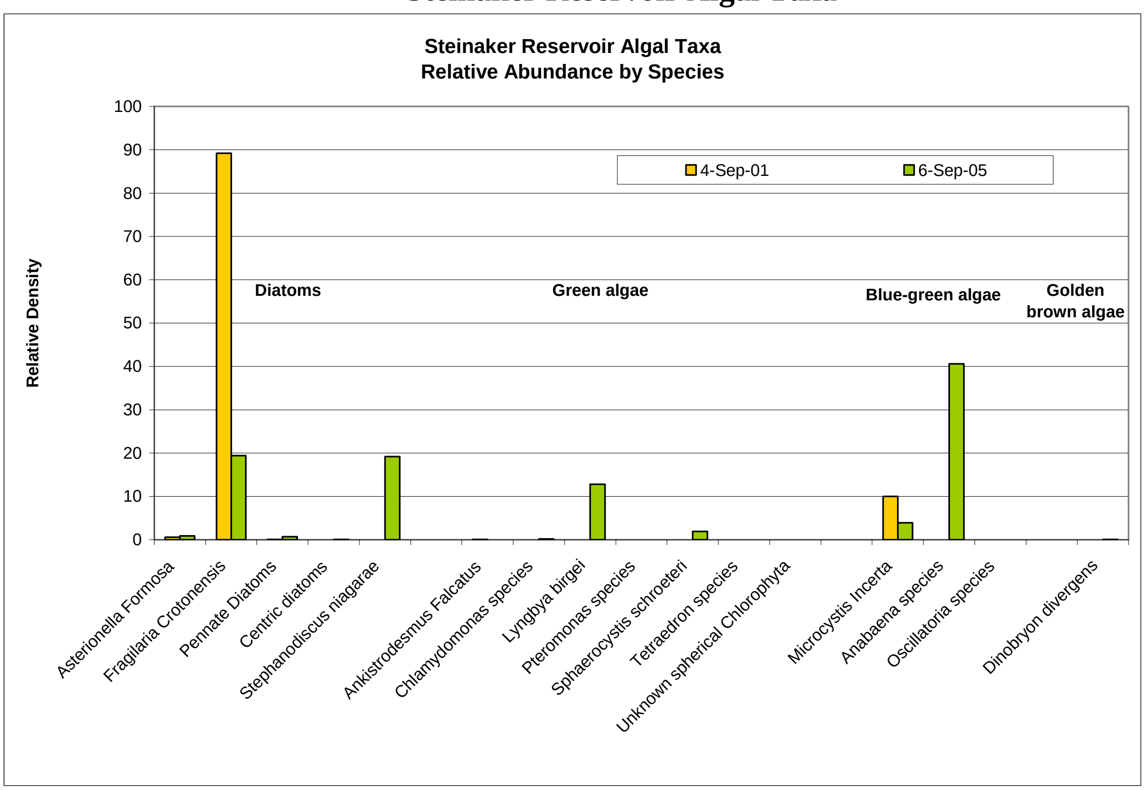


The negative values on the "TSI CHL – TSI TP" axis may also indicate that phosphorus in not the limiting nutrient. For Steinaker Reservoir, the average "pseudo" N:P ratio was calculated as 5.8 with 30% of the samples greater than 7.2. This indicates that phosphorus is the limiting nutrient much of the time, and perhaps most of the time depending on the extent to which the "pseudo" N:P ratio underestimates the true N:P ratio.

4.3.7 Phytoplankton Assessment

Phytoplankton data were collected from the euphotic zone in September 2001 and 2005 (Figure 20). The types of taxa identified in the sample in 2001 indicate the phytoplankton community was dominated by the diatom species (*Fragilaria crotonensis*) with a low relative density of blue green algae (*Microcystis incerta*). Diatoms comprised 90 % of the sample. In 2005, the cyanophyta (*Anabena* species), an algal indicator of eutrophy, was found in 40% of the sample, 40% of the sample contained the diatom species with the remainder in green algae. Though these 2 samples reflect the biological condition at a point in time they do not address seasonal phytoplankton succession nor can definitively address phytoplankton species composition changes in relation to trophic status over time.

Figure 20
Steinaker Reservoir Algal Taxa



4.3.8 Sediment Oxygen Demand

The rate of sediment oxygen demand (SOD) occurring in each reservoir can be estimated from historically observed data defining the decrease in hypolimnetic dissolved oxygen over the course of a summer (i.e. DO depletion rates).

SOD (g/m2/day) = [Observed DO depletion rate – DO depletion due to water column demand] x Water Depth.

The above equation is based on the fact that oxygen depletion in the hypolimnion is caused by two separate sources: 1) oxygen depletion due to water column BOD and algal respiration, and 2) oxygen depletion due to SOD. The observed oxygen depletion rate reflects the combined effect of both sources. The SOD component can therefore be calculated by subtracting the water column component from the observed total. Chapra (1997) indicates that it can be assumed that SOD is the primary cause of hypolimnetic oxygen depletion, such that the water column contribution can be ignored in the equation above. SOD calculations for Steinaker Reservoir are provided below.

Table 46
Steinaker Reservoir SOD

Observed DO Depletion rate ($g/m^3/day$)	Hypolimnetic Depth (m)	Estimated SOD ($g/m^2/day$)
0.023	6.4	0.54

While there are no definitive guidelines, an estimated SOD of 0.6 $g/m^2/day$ would be considered indicative of a mesotrophic lake.

4.3.9 Seasonality

These TMDL calculations were conducted with an explicit consideration of seasonal variation. The BATHTUB model is designed to evaluate seasonal to annual loads. Annual loads were calculated by summing the individual daily loads over the course of a year, and fully capturing seasonal variability. The annual loading analysis that was used is appropriate due to the long response time between phosphorus loading and biotic response.

5.0 CONCLUSIONS

The following conclusions can be drawn for all three reservoirs:

- All three reservoirs are not meeting the State water quality standard for dissolved oxygen, as it is currently being interpreted for deep reservoirs (at least 4 mg/L in at least 50% of the water column). Although the depressed dissolved oxygen levels have not resulted in fish kills at any of these reservoirs. Review of observed temperature and dissolved oxygen data shows that an area of refuge containing acceptable temperature and dissolved oxygen exists in all three reservoirs.
- The reservoirs all exhibit atypical behavior regarding the relationship between nutrient loading and resulting oxygen concentrations. The amount of hypolimnetic oxygen demand determined by the BATHTUB modeling results is higher than what would be expected from the observed chlorophyll concentrations; however, the amount of algae present is lower than what would be expected from the observed phosphorus concentrations.
- The expected amount of phosphorus load reduction required to reduce sediment oxygen demand to levels that comply with the water quality standard based on the BATHTUB modeling results cannot be feasibly attained.

The remainder of this section expands upon the above summary and is divided into sections corresponding to Impairment Status and Causes/Remedies.

5.1 Impairment Status

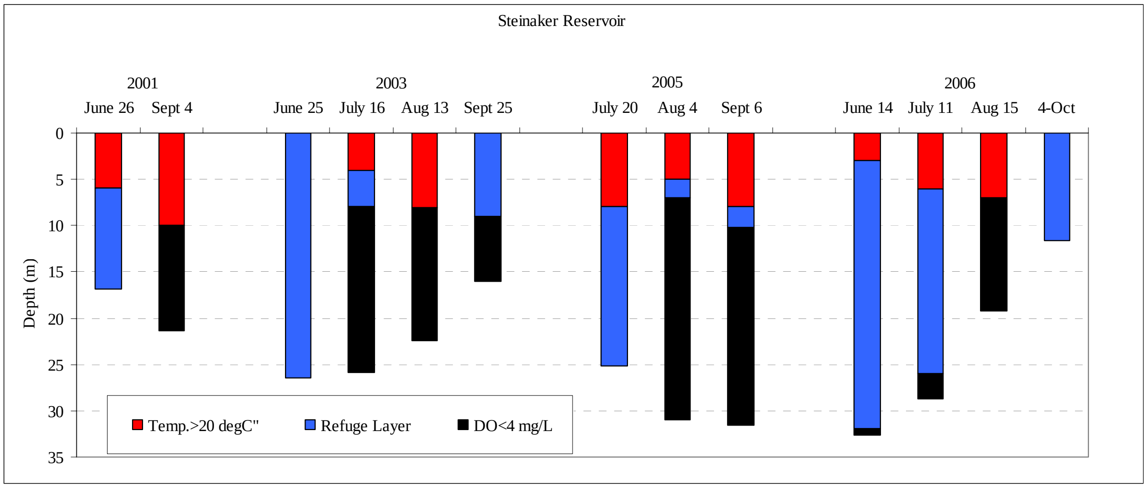
All three reservoirs are not complying with the State water quality standard for dissolved oxygen (as it is currently being interpreted for deep reservoirs). Data from Brough Reservoir demonstrated partial support status during five sampling events and non-support status during two sampling events. Data from Red Fleet Reservoir demonstrated partial support status during five sampling events. Data from Steinaker Reservoir demonstrated partial support status during six sampling events and non-support status during one sampling event.

Seasonal stratification in reservoirs characterized by high temperatures in the epilimnion coupled with anoxic conditions in the hypolimnion can limit suitable cold-water fish habitat at the thermocline. When temperatures are too warm and no dissolved oxygen exists for a prolonged period of time the fish are stressed and a fish kill can occur. Fish kills have not been observed at any of these reservoirs, despite the continued presence of low dissolved oxygen. Further review of observed temperature and dissolved oxygen data shows that an area of refuge containing acceptable temperature and dissolved oxygen exists in all three reservoirs.

To identify the extent of the refuge layer for fish at the thermocline which is defined as the portion of the epilimnion which is less than 20°C (Utah water quality standard for maximum water temperature for cold water fishery beneficial use) and the portion of the hypolimnion which has dissolved oxygen levels greater than 4.0 mg/L, the water column data were analyzed from 1999 to 2006 during the summer season. Under these standards, for Steinaker reservoir (Figure 21) at least one meter is available for the fish to reside at the thermocline with the exception of August 2003 and 2006, two drought years with no reported fish kills. For Red Fleet reservoir (Figure 22), at least two meters is available for fish habitat in all years. Brough Reservoir (Figure 23) stratifies earlier, typically in July with no suitable fish habitat in August in all years when the reservoir is drained to the conservation pool.

Rainbow Trout is the most sensitive species in the reservoirs to warm temperatures. According to the Handbook of Freshwater Fishery Biology, the range of temperatures for Rainbow Trout is 0°C to 28°C with an optimum of 21°C although spawning and growth occur from 9°C to 14°C. Since the reservoirs are stocked heavily every year with catchable rainbow trout, concerns for spawning are not applicable. The US EPA Goldbook water quality criteria for temperature (http://www.epa.gov/waterscience/criteria/goldbook.pdf) states that "In the warmer months (April through October in the north and March through November in the south) is [sic] determined by adding to the physiological optimum temperature (usually for growth) a factor calculated as one-third of the difference between the ultimate upper incipient lethal temperature and the optimum temperature or the most sensitive important species (and appropriate life state) that normally is found at that location and time". As stated this would result in a seasonal species specific temperature limit of 21°C + (28°C-21°C)/3 = 23.33°C. When the water column data during the summer season were reevaluated for the portion of the epilimnion less than 23 degrees (see figures below) a refuge layer existed in all months in all years for all three reservoirs. Though the reservoirs are not listed on the 303 (d) list for temperature, this analysis (thermal regime and dissolved oxygen) was conducted to assure the survival of the fish populations during a time of deep stratification, maximum water withdrawal and high temperatures.

Figure 21
Steinaker Reservoir Refuge Layers



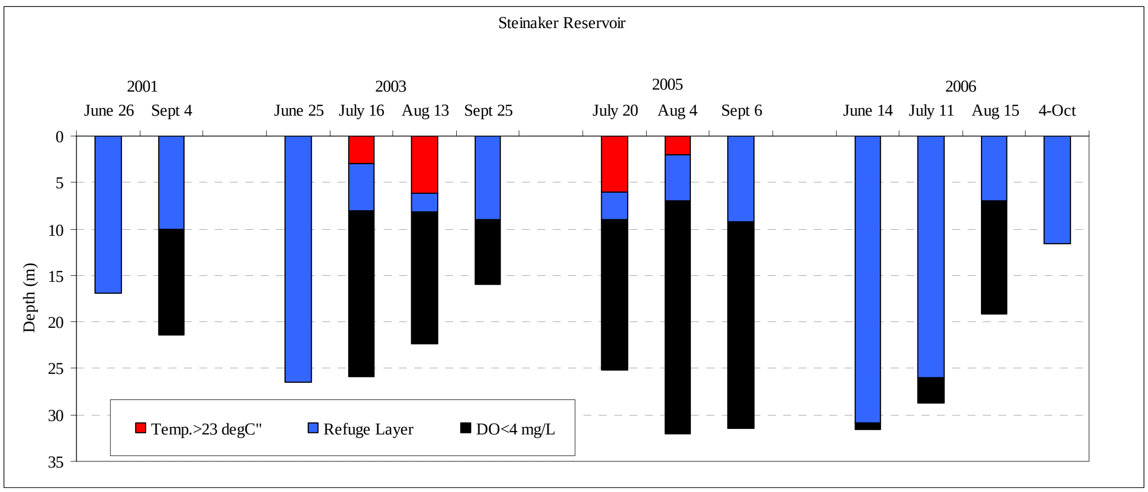
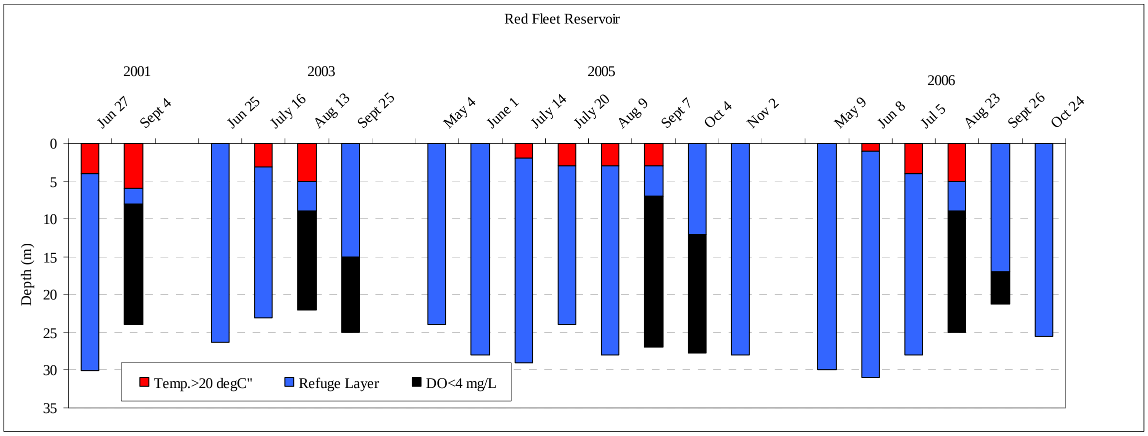


Figure 22
Red Fleet Reservoir Refuge Layers



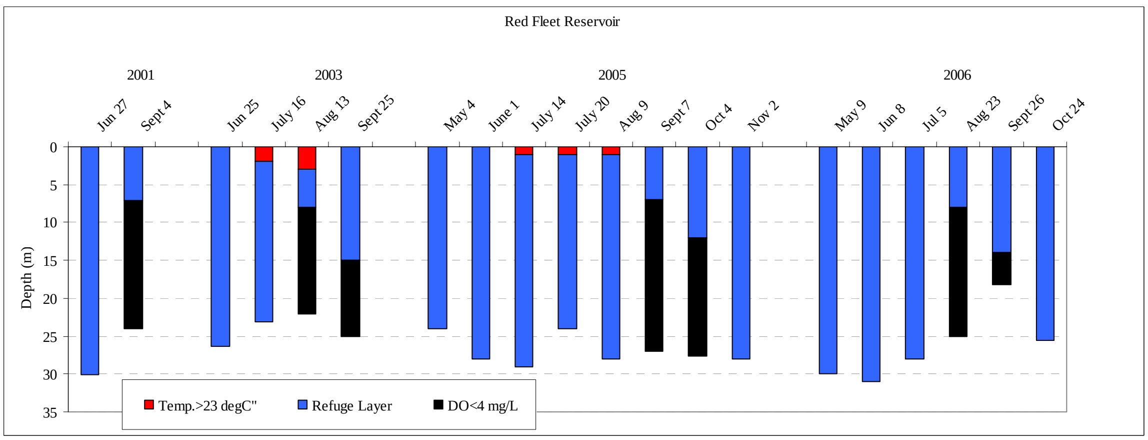
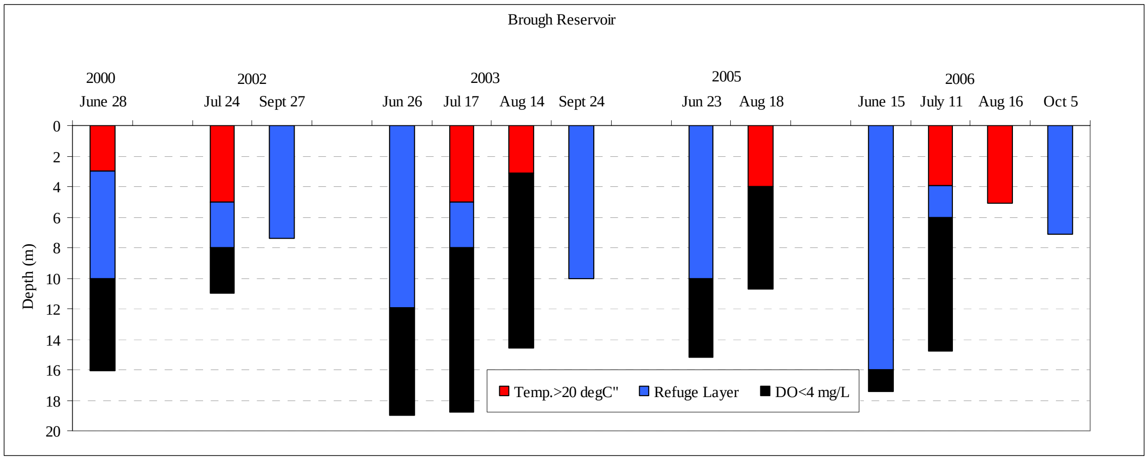
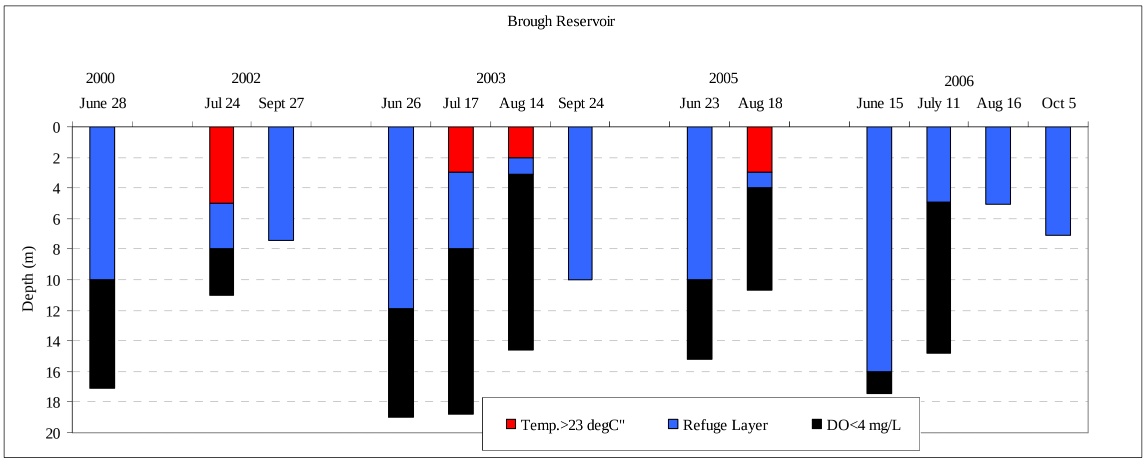


Figure 23
Brough Reservoir Refuge Layers





5.2 Causes/Remedies

The typical cause of hypolimnetic oxygen problems consists of excess nutrients contributing to increased algal growth, with algae settling from the surface layers and consuming oxygen in the hypolimnion. This is typically addressed by management intervention to control the external load of the limiting nutrient, which therefore restricts algal growth and the subsequent hypolimnetic oxygen depletion. In most lakes, either nitrogen or phosphorus is clearly the limiting nutrient. In these three reservoirs, it appears that both of these nutrients may serve as the limiting nutrient at different times. Phosphorus is typically preferred as the nutrient to be controlled in these situations, because phosphorus loads are generally more amenable to management control than nitrogen loads.

The reservoirs all exhibit relatively atypical behavior regarding the relationship between nutrient load and resulting oxygen concentration. The observed amount of hypolimnetic oxygen demand is higher than what would be expected from the observed chlorophyll concentrations. The observed hypolimnetic oxygen demand is more than double what is expected from the observed chlorophyll in Red Fleet and Steinaker Reservoirs; it is roughly 35% higher than what is expected for Brough Reservoir. The reasons for this elevated oxygen demand are not clear, but may be attributed in part to the large extent to which the reservoirs are drawn down each summer. This drawdown serves to both intensify the effect of the SOD and increase its magnitude by exposing the lake bed and facilitating plant growth.

The amount of algae present is lower than what would be expected from the observed phosphorus concentrations. This indicates that other factors besides phosphorus availability may play a role in controlling algal growth. Review of the trophic status index data indicates that non-algal turbidity may play a role in limiting algal growth. This would be consistent the phenomenon mentioned above of fine, organic-rich particles being eroded from the watershed and remaining in suspension in the water column, before settling and contributing to sediment oxygen demand. The likely occurrence of nitrogen limitation at certain times of the year may also partially explain why chlorophyll concentrations are less than what would be predicted by phosphorus alone.

The observed rates of oxygen depletion are substantially larger than the rates necessary to obtain compliance with the water quality standard for dissolved oxygen. The observed oxygen depletion rates in Red Fleet and Steinaker Reservoirs are more than double what is needed to meet the water quality standard, while the observed oxygen depletion rates in Brough Reservoir is more than triple what is needed to meet the standard. These high oxygen demands (relative to what is allowed by the standards), combined with the relatively weak relationship between reduction in phosphorus loads and reduction in algae, combine to result in extremely large reductions in phosphorus loads to attain the dissolved oxygen standard. The expected amount of phosphorus load reduction required to reduce sediment oxygen demand to levels that comply with the water quality standard is so large for all three reservoirs that it cannot be feasibly attained.

The cause of the dissolved oxygen impairments have been primarily attributed to the draw down of reservoir levels during the late summer which suggests that an alternative tiered beneficial use classification for these types of waterbodies would be appropriate. Pending development of a tiered aquatic life use and due to the fact there is adequate refugia in all three reservoirs during the critical period, no reported fish kills, no discernable trend of declining water quality and the unattainable load reductions produced by the modeling effort it is recommended that these be considered phased TMDLs. A phased implementation approach for these TMDLs will include continued monitoring of the reservoirs as well as development of tiered aquatic life uses that will include appropriate assessment methods and water quality standards to more accurately assess beneficial use support for these unique waterbodies.

5.3 Load Allocations

The TMDL load allocation assigns loads to all sources including point, non-point and background sources. In addition, a margin of safety (MOS) is included to account for the uncertainty inherent in the analysis and ensure that beneficial uses are protected into the foreseeable future. The MOS is a required part of the TMDL development process. There are two basic methods for incorporating the MOS (USEPA, 1991). Implicit methods incorporate the MOS using conservative model assumptions to develop allocations. Explicit methods specify a portion of the total TMDL as the MOS, allocating the remainder to sources. For the Brough, Red Fleet, and Steinaker Reservoir TMDLs, the MOS was included implicitly through conservative assumptions. The total phosphorus load allocations for each reservoir are listed in Table 47.

Table 47
Total Phosphorus TMDL Load Allocations (kg/year)

Source	Current	Allocation	Reduction	Margin of Safety
Brough Reservoir	298	9	289	Implicit
Red Fleet Reservoir	1,489	150	1,339	Implicit
Steinaker Reservoir	777	22	755	Implicit

5.4 Public Participation

Public participation for this TMDL was accomplished through a series of open meetings on April 12, 2007 at the County/State Building in Vernal, Utah; and on April 13, 2007 at the USDA Service Center in Roosevelt, Utah.

Public comment on the TMDLs was solicited with a notice published in the Salt Lake Tribune on February 11, 2008. The comment period was opened on February 11 and closed on March 10, 2008. Comments and responses are included in Appendix 13.

In addition, the TMDL and dates for public comment were posted on the Division of Water Quality's website at http://www.waterquality.utah.gov/PublicNotices.

5.5 Monitoring

Under the Division's lake and reservoir assessment program these waterbodies and their tributaries will be sampled twice every other year. The objectives of this monitoring plan will be to determine existing water quality conditions, evaluate water quality trends, and establish achievable water quality goals through the development of tiered aquatic life uses. The purpose of this monitoring plan will be to provide productivity data including lake transparency values, phosphorus concentrations and chlorophyll-a levels and other chemical and physical parameters including dissolved oxygen, temperature, and pH.

Brough Reservoir will be sampled during even years (2008, 2010, etc.) at two locations on the reservoir (Storet Sites 5932430 and 5932440) and at the tributary site, Canal above Brough Reservoir (Storet Site 5932450). Steinaker and Red Fleet Reservoirs will be sampled during odd years (2009, 2011, etc.) at two locations on Steinaker Reservoir (Storet Sites 4937550 and 4937570) and at three locations on Red Fleet Reservoir (Storet Sites 5937650, 5937660, and 5937730). The tributary sampling location for Steinaker Reservoir is Steinaker Ditch above Steinaker Reservoir (Storet Site 4937520) and the tributary sampling location for Red Fleet Reservoir is Big Brush Creek above Red Fleet Reservoir (Storet Site 4937860).

6.0 REFERENCES

Bureau of Land Management, 2005a. Draft Vernal Resources Management Plan Synopsis, available at: (http://www.ut.blm.gov/vernalrmpguide/mineral_resources.htm)

Bureau of Land Management, 2005b. Vernal Resources Management Plan, Draft Environmental Impact Statement, available at: http://www.ut.blm.gov/vernalrmpguide/Chapter 3/Hazardous Materials-Chapter3.pdf.

BOR, 2007 Reclamation Managing Water in the West – Steinaker Reservoir Normal Water Surface Elevation Increase draft Environmental Assessment PRO-EA-07-01. Central Utah Project – Vernal Unit. Uintah County, Utah. Upper Colorado Region – Provo Office. August 2007.

Carlander, Kenneth, 1997. Handbook of Freshwater Fishery Biology Volume 1. The Iowa State University Press, Ames Iowa

Carlson, R.E. and J. Simpson. 1996. A Coordinator's Guide to Volunteer Lake Monitoring Methods. North American lake Management Society. 96 pp.

Chapra, S.C. 1997. Surface Water Quality Modeling. McGraw-Hill Companies, Inc. Boston, MA.

EPA, 1986. Quality Criteria for Water 1986. EPA 440/5-86-001. Office of Water Regulations and Standards. Washington DC, 20460.

Judd, H.L. 1997. Utah Lakes and Reservoirs. Inventory and Classification of Utah's Priority Lakes and Reservoirs. Utah Dept. of Environmental Quality. Clean Lakes Study in Cooperation with U.S. Environmental Protection Agency, Region III. January 1997.

Stokes, W.L., 1986. Geology of Utah, pub by Utah Museum of Natural History, University of Utah and Utah Geological and Mineral Survey, Department of Natural Resources, 280 pp.

USGS, 1996. The Mineral Industry of Utah. Prepared under a Memorandum of Understanding between the U.S. Bureau of Mines, U.S. Department of the Interior, and the Utah Geological Survey. Available at: http://minerals.usgs.gov/minerals/pubs/state/984997.pdf

USGS. Water Resources of Utah. http://ut.water.usgs.gov/

Utah Administrative Code R317-2. Standards of Quality for Waters of the State. January 1, 2007.

Utah Department of Water Resources. 2004 Groundwater Conditions in Utah. Cooperative Investigations. Report No. 45.

Utah DWQ. 2000. Utah's 2000 303(d) List of Waters. Utah Department of Environmental Quality - Division of Water Quality. October 2000.

Utah DWQ. 2004. Utah's 2004 303(d) List of Impaired Waters. Utah Department of Environmental Quality - Division of Water Quality. April 1 2004.

Utah DWQ. 2005. Utah's Lakes and Reservoirs. Brough Reservoir. http://www.waterquality.utah.gov/watersheds/lakes/BROUGH.pdf

Utah DWQ. 2005. Utah's Lakes and Reservoirs. Red Fleet Reservoir. http://www.waterquality.utah.gov/watersheds/lakes/RED FLEET.pdf

Utah DWQ. 2005. Utah's Lakes and Reservoirs. Steinaker Reservoir. http://www.waterquality.utah.gov/watersheds/lakes/STEINAKER.pdf

Utah DWQ. 2006. Utah's 2006 Integrated Report Volume II - 303(d) List of Impaired Waters. Utah Department of Environmental Quality - Division of Water Quality. April 2006.

Western Regional Climate Center. Desert Research Institute. Reno, Nevada. http://www.wrcc.dri.edu/