NINE MILE RESERVOIR

LIMNOLOGICAL ASSESSMENT OF WATER QUALITY

Utah Division of Water Quality

February 2008

Utah Department of Environmental Quality
Division of Water Quality
TMDL Section

Nine Mile Reservoir

Waterbody ID	Nine Mile Reservoir UT-L-16030004-001
Location	Sanpete County, Central Utah
Pollutants of Concern	Low dissolved oxygen Excess total phosphorus
Impaired Beneficial Uses	Class 3A: Protected for cold water species and their food chain.
Recommended Action	Nine Mile Reservoir is recommended to be placed in Category 5B of the State of Utah's 303(d) list and requested for removal from the current listing of impaired waters.
Delisting Rationale	• Recent data assessment indicates that the water body is supporting all of its designated beneficial uses. • There have been no observed dissolved oxygen exceedances (> 50% of the water column maintained above 4 mg/L) since 1999. • Average current total phosphorus values (1999–2006) are below the threshold of 0.025 mg/L established by the State of Utah for reservoirs. • Both monitoring data and simulation modeling indicate that the reservoir is mesotrophic and is not at risk for eutrophication. • Water quality in the reservoir shows a trend toward improvement as measured by total phosphorus, chlorophyll *a* and Secchi depth. • A comparison with nearby Palisades Lake, which is not listed as impaired, indicates that water quality is generally better in Nine Mile Reservoir with the important exception of pH exceedances. • Exceedances of pH criteria are associated with naturally alkaline soils underlying the reservoir and its watershed. • Exceedances of temperature criteria are related to drought conditions, exposure, and natural climatic factors in the San Pitch basin. • No fish kills have been reported in Nine Mile Reservoir. • Blue-green algal species are not prevalent in Nine Mile Reservoir.

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Under section 303(d) of the Clean Water Act, Nine Mile Reservoir has been identified as water quality limited due to low dissolved oxygen and excess phosphorus loading to the reservoir from the surrounding watershed. The State of Utah has designated the beneficial uses of the reservoir as secondary contact recreation (2B), cold water game fish and the associated food chain (3A), and agricultural water supply (4). The cold water game fish designated use (3A) was identified as not supported on the State of Utah's 2006 303(d) list of impaired waters. However, analysis of current water quality in Nine Mile Reservoir and its tributaries indicates that the reservoir is meeting all designated beneficial uses. Since anthropogenic activities are not impairing water quality, Nine Mile Reservoir is recommended to be placed in Category 5B of the State of Utah's 303(d) list and requested for removal from the current listing of impaired waters. The following rationales are presented to support this recommendation.

- An assessment of recent data indicates that the water body is supporting all of its designated beneficial uses; there have been no observed dissolved oxygen exceedances since 1999.
- Current total phosphorus values (1999–2006) are well below the threshold of 0.025 mg/L established by the State of Utah for reservoirs when standard methods are used to include nondetect values and exclude outliers from the dataset.
- Both monitoring data and simulation modeling indicate that the reservoir is mesotrophic and is not at risk for eutrophication.
- Water quality in the reservoir shows a trend toward improvement as measured by total phosphorus, chlorophyll *a* and Secchi depth.
- A comparison with nearby Palisades Lake, which is not listed as impaired, indicates that water quality is generally better in Nine Mile Reservoir with the important exception of pH exceedances.
- Exceedances of pH criteria are associated with naturally alkaline soils underlying the reservoir and its watershed.
- Exceedances of temperature criteria are related to drought conditions, exposure, and natural climatic factors in the San Pitch basin.
- No fish kills have been reported in Nine Mile Reservoir.
- Blue-green algal species are not prevalent in Nine Mile Reservoir.

Acknowledgments

SWCA staff gratefully acknowledges the time and effort that have been dedicated by so many individuals and organizations whose help and support have been indispensable. Their continuing support is very much appreciated.

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1 INTRODUCTION

1.1 SUMMARY OF IMPAIRMENT LISTING FOR NINE MILE RESERVOIR

Under section 303(d) of the Clean Water Act (CWA), Nine Mile Reservoir has been identified as water quality limited due to low dissolved oxygen and excess phosphorus loading to the reservoir from the surrounding watershed. The State of Utah has designated the beneficial uses of the reservoir as secondary contact recreation (2B), cold water game fish and their associated food chain (3A), and agricultural water supply (4). The cold water game fish designated use (3A) was identified as non-supported on the State of Utah 2006 303(d) list. Secondary contact recreation and agricultural water supply designated uses were reported as being fully supported on this same list.

1.2 THE TOTAL MAXIMUM DAILY LOAD (TMDL) PROCESS

A Total Maximum Daily Load (TMDL) is the amount of an identified pollutant that a specific stream, lake, river or other water body can 'accommodate' without violating state water quality standards. TMDLs are watershed-based plans for restoring designated beneficial uses in water quality limited water bodies. These plans must identify the causes of designated beneficial use impairment, estimate reductions in pollutant loads necessary to meet water quality standards, and restore impaired designated beneficial uses within a specified time.

Briefly, the TMDL process involves evaluating the available data from 303(d) listed water bodies to determine point and nonpoint source pollution loads and using the data to set maximum allowable loads from each of these sources. Loads are the quantity of pollution contributed to a stream by a single source (e.g., a wastewater treatment plant) or by a group of sources (e.g., all developments or agricultural fields along a stream).

In this framework, a TMDL can be best described as a watershed or basin-wide budget for pollutant loading to a watercourse. A TMDL, in actuality, is a planning document. The "allowable budget" is first determined by scientific study of a stream to determine the amount of pollutants that can be assimilated without causing the stream to exceed the water quality standards set to protect the stream's designated beneficial uses (e.g., game fish, domestic water supply, etc.). This amount of pollutant loading is known as the *loading capacity*. It is established taking into account seasonal variations, natural and background loading, and a margin of safety. Once the loading capacity is determined, sources of the pollutants are considered. Both *point* and *nonpoint sources* must be included. As part of this process, habitat function is assessed to provide a qualitative summary of the current support status of game fish beneficial uses.

1.3 DELISTING REQUIREMENTS UNDER THE CLEAN WATER ACT

Analysis of current water quality in Nine Mile Reservoir and its tributaries indicate that the reservoir is meeting all designated beneficial uses. Since man-made activities have not caused any water quality impairment, Nine Mile Reservoir is recommended to be placed in Category 5B of the State of Utah's 303d list and petitioned for removal from the current 303(d) listing of impaired waters.

According to EPA regulations, each state must demonstrate good cause for not including waters on the list (40 CFR. Part 130.7(b)(6)(iv)) or removing them from the list. These include:

- A water body listed due to error in assessment, a water body listed incorrectly in place of another water body, or any other error not based on a water quality assessment.
- The most recent data assessment indicates that the water body is supporting all of its designated beneficial uses.
- A total maximum daily load analysis has been completed and approved by the EPA.
- New modeling information indicates no TMDL is required in order to maintain water quality standards.
- Data assessment methodologies have been modified.

Utah may also request EPA delisting of a water body when:

- The water body is meeting all applicable water quality standards or is expected to meet these standards in a reasonable time frame (e.g., two years) as a result of implementation of required pollutant controls.
- Upon re-examination, the original basis for listing is determined to be inaccurate.

Of the criteria listed above, the following were used in the impairment assessment of Nine Mile Reservoir leading to a recommendation for delisting. Analysis of recent dissolved oxygen and phosphorus data indicate full support of beneficial uses and watershed and reservoir models indicating that no TMDL is required in order to maintain dissolved oxygen water quality standards. The Nine Mile Reservoir watershed has been meeting all listed beneficial uses set by the State of Utah. Based upon available data and computer model simulations, the impairment listing for dissolved oxygen is not supported and therefore the reservoir should be removed from the Utah 303 (d) list.

2 CHARACTERIZATION OF WATERSHED

2.1 PHYSICAL AND BIOLOGICAL CHARACTERISTICS

The Nine Mile Reservoir study area is located in Sanpete County, in central Utah between the towns of Sterling and Gunnison (Figure 2.1). The reservoir and its drainage area form a portion of the San Pitch River basin. The reservoir shoreline is privately owned by the Gunnison Irrigation Company with unrestricted public access. The watershed is a mixture of public and private land with land uses that include range, agriculture and rural development. The uplands are predominately administered by the U.S. Forest Service while the valley floor is privately owned pasture and cropland.

The primary land uses in the watershed are agriculture (cattle and sheep grazing, hayland and pasture) and rural residential housing. Sedimentation and nutrient loading are the major potential sources of nonpoint source pollution. There are no point source pollution sources to the reservoir (UDWQ 2007). Major inflows to the reservoir include Six Mile Creek (diverted to the reservoir for a portion of the year) and three natural springs located along the eastern shore of the reservoir. UDWR stocks Nine Mile Reservoir with rainbow trout, tiger trout (a brown trout / brook trout hybrid). The reservoir also contains non-native smallmouth bass and crayfish.

Nine Mile Reservoir is located at the western base of the Wasatch Plateau at an elevation of 5,402 ft (1,646 m). The reservoir has a maximum volume of approximately 3,500 acre-feet of water. Maximum reservoir depth is approximately 11 meters, and the reservoir shoreline extends 14,169 feet (4,320 m). Slopes within this watershed are complex, and range from 0 to 45 degrees with an average slope in the direct drainage of the reservoir of 10 degrees. The average slope in the Six Mile Creek watershed is 16.5 degrees with a range from 0 to 77 degrees. The highest point in the watershed is located near the headwaters of Six Mile Creek along Skyline Drive at an elevation of 10,700 feet. The lowest point is the reservoir outlet at an elevation of approximately 5,360 feet.

The earth-fill dam that forms the reservoir was completed in 1900 and rises to a structural height of 46 feet (Utah Division of Water Rights 2006a). The reservoir is used for storing irrigation water and recreation. Anecdotal information indicates that Nine Mile Reservoir has been filled to capacity (3,500 acre-feet) most years and is often drawn down to below the staff gage which records a minimum volume of 240 acre-feet. There is no conservation pool established for this reservoir. The physical structure of the reservoir is such that the elevation of the outlet does not allow full evacuation of all water behind the dam, thus, even in low water years, a minimum of approximately 100 acre-feet of water will remain in the reservoir.

2.1.1 CLIMATE

Climate in the Nine Mile Reservoir drainage basin ranges from semiarid in Sanpete Valley to subhumid in the surrounding uplands. The area is characterized by large seasonal and daily temperature variations, especially during the summer. Most of the precipitation in the San Pitch River drainage basin falls as snow in the mountains, particularly along the Wasatch Plateau, from November to April. The months of June through August are generally the driest, although brief, intense thunderstorms can produce locally large precipitation totals.

The Nine Mile Reservoir watershed is generally hot and dry in the summer and cold and dry in the winter. Precipitation is bimodal (peaking in March and September or October) with intense, short duration summer storms and milder, longer duration winter storms. Much of the water is derived from snowmelt runoff from high elevations along the Wasatch Plateau and headwaters of the inflowing tributaries. Snow pack accumulation generally occurs from November to April at higher elevations. Lower areas of the valley receive between 10 inches (25 cm) and 14 inches (35.6 cm) of precipitation annually, while elevations above 8,000 feet (2,500 meters) average approximately 24 inches (60 cm) of precipitation annually. Average annual evaporation in the San Pitch River drainage is 3.5 times greater than the average annual precipitation (Robinson 1971).

Climate data are not available directly for the reservoir. However, two long-term climate sites maintained by the Western Regional Climate Center (WRCC) are available near the watershed boundaries at Manti, Utah, and Gunnison, Utah.

The Manti, Utah WRCC site is located at an elevation of 5,530 feet (1,815 meters), approximately 8 miles northeast of the reservoir and is assumed to be generally representative of conditions at the reservoir site (reservoir elevation is 5,402 feet (1,646 meters). The site has been in operation from January 1928 to present, and data are available through to December 2005 (WRCC 2006). Average and extreme minimum and maximum temperatures recorded over the period of record for the Manti, Utah WRCC site are displayed in Table 2.1 and Figure 2.2. Average total monthly precipitation for this site is displayed in Table 2.2 and Figure 2.2.

As the Manti, Utah WRCC site is located to the northeast of the watershed and may not be fully representative of conditions in southwestern areas, additional data were collected from the WRCC site located near Gunnison, Utah.

Table 2.1 Manti, Utah Air Temperature Data Summary

	Monthly Average			Extreme High (°F)		Extreme Low (°F)	
	Max (°F)	Min (°F)	Average (°F)				
Annual	61.7	33.8	47.7	103	Jul 1960	-27	Jan 1937
Winter	39.2	16.9	28.1	69	Feb 1986	-27	Jan 1937
Spring	60.4	32.5	46.4	90	May 1967	-5	Mar 1964
Summer	83.6	51.3	67.4	103	Jul 1960	27	Jun 1902
Fall	63.6	34.4	49.0	97	Sep 1950	-18	Nov 1931

Winter = December, January, and February; Spring = March, April, and May; Summer = June, July, and August; Fall = September, October, and November. (WRCC data, period of record = 1928 to 2006)

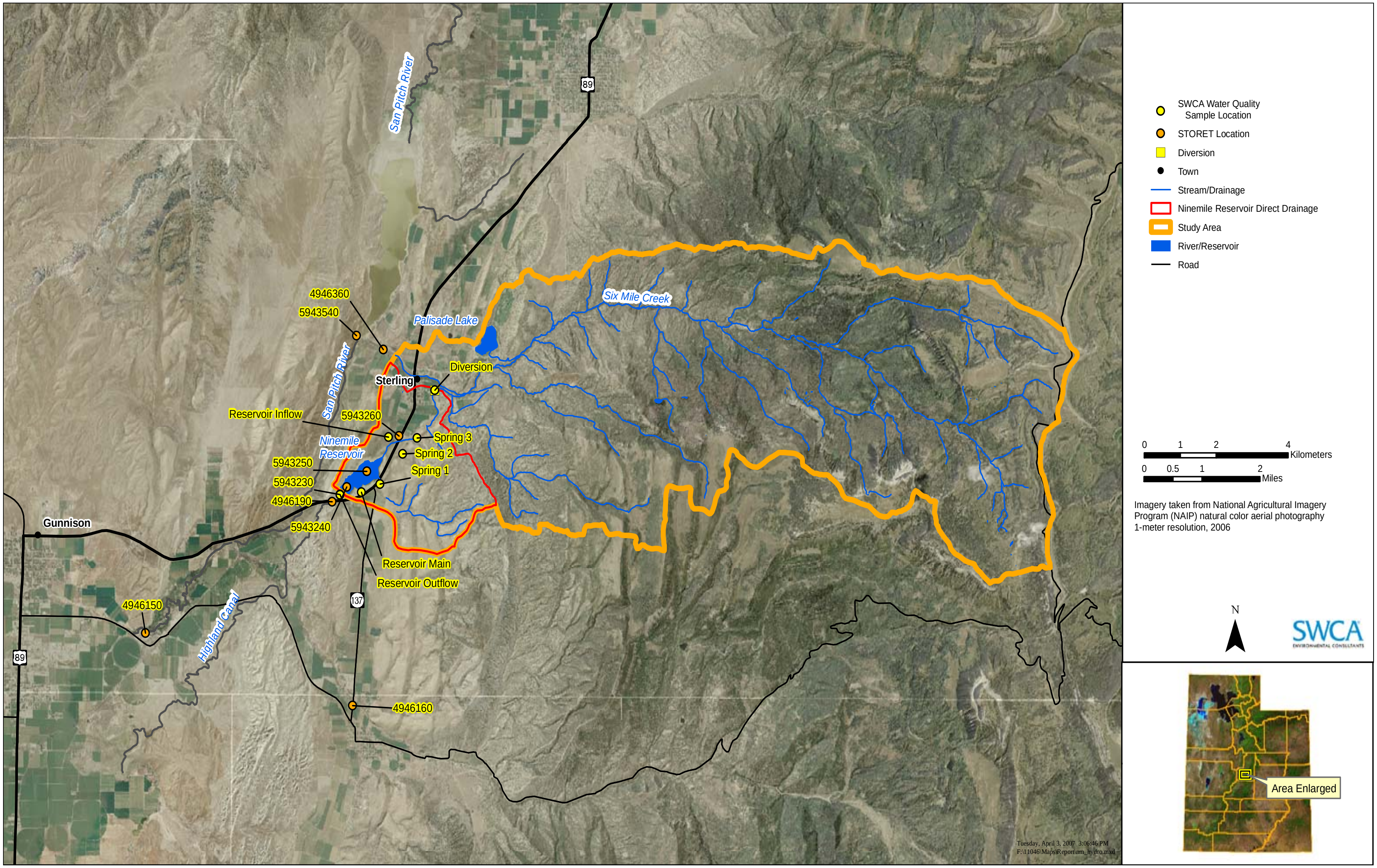


Figure 2.1 Study area with the Nine Mile Reservoir watershed.

Table 2.2 Manti, Utah Precipitation Data Summary

	Average (inches)	High (inches)		Low (inches)	
Annual	12.87	21.55	1983	7.08	1934
Winter	3.13	6.16	1980	0.89	1931
Spring	3.97	9.47	1995	1.34	1934
Summer	2.48	6.80	1936	0.31	1931
Fall	3.29	8.80	1982	0.56	1932
Winter = December, January, and February; Spring = March, April, and May; Summer = June, July, and August; Fall = September, October, and November. (WRCC data, period of record = 1928 to 2006)					

The Gunnison, Utah WRCC site is located at an elevation of 5,125 feet (1,682 meters), approximately 6 miles to the west-southwest of the reservoir and is representative of both the general reservoir location and the topography and elevation of much of the Nine Mile watershed. The site was in operation from March 1956 to April 1990 (WRCC 2006). Average and extreme minimum and maximum temperatures recorded over the period of record for the Gunnison, Utah WRCC site are displayed in Table 2.3 and Figure 2.3. Average total monthly precipitation for this site is displayed in Table 2.4 and Figure 2.3.

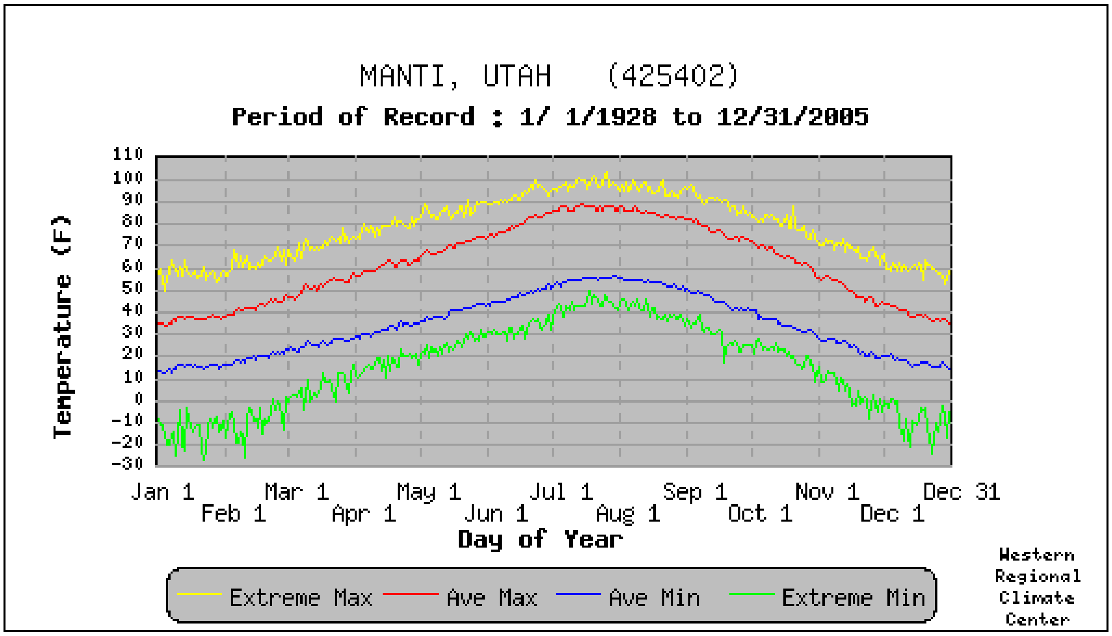
Observed temperatures at the Gunnison, Utah WRCC site are slightly warmer and precipitation somewhat lower than those observed at the Manti, Utah site. The Gunnison, Utah site experiences warmer maximum temperatures by about 3 to 5°F (15–16°C), and cooler minimum temperatures by about 3°F (15°C) than the Manti, Utah site. Annual average precipitation is approximately 30% lower at the Gunnison, Utah site than that observed at the Manti, Utah site. The differences in temperature and precipitation observed between these two locations provide a relative variance for the lower watershed elevations.

Mean precipitation data for a larger general area near Nine Mile Reservoir are available from 13 SNOTEL sites managed by the Utah Division of Water Resources. Data are available from 1996 to 2006 and include a 10-year average.

No SNOTEL sites are located directly within the Nine Mile Reservoir watershed. The closest SNOTEL station is Seeley Creek (Station ID: 11k09s) located near Twelve Mile Creek approximately 3 miles from the south-central boundary of the watershed, about 8 linear miles east of the reservoir. The SNOTEL site elevation is approximately 9,910 feet and is assumed to be characteristic of climate conditions in the higher elevations within the watershed.

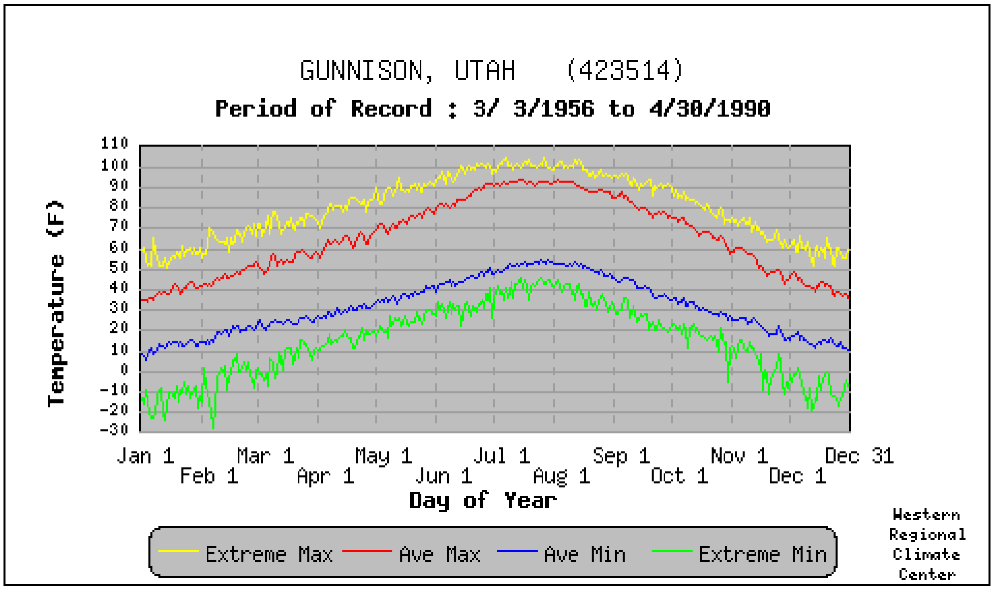
Station data indicate that in the past 10 years, the average annual precipitation is 24.7 inches (62.74 cm) with a minimum of 17.3 inches (43.94 cm) recorded in 2002 and maximum of 31.8 inches (80.77 cm) falling in 1998. Precipitation falls throughout the fall, winter, and spring with lower precipitation rates in the summer months (May, June, July, and August). The area is subject to high intensity thunderstorms in the summer. Mean monthly high temperatures at the SNOTEL station from 1997 to 2006 range from 40.6°F (-1°C) in the winter to 75.7°F (22°C) in the summer.

The Nine Mile Reservoir watershed has experienced drought for much of the last five years, with extremely dry conditions occurring during the summer of 2002, when the Palmer Drought Severity Index (PDSI) reached near-record severity based on the last 100 years of instrumental data (NCDC 2004). These dry conditions have resulted in low water and low flow conditions for the reservoir watershed and adjacent areas.



- **- Extreme Max. is the maximum of all daily maximum temperatures recorded for the day of the year.**
- **- Ave. Max. is the average of all daily maximum temperatures recorded for the day of the year.**
- **- Ave. Min. is the average of all daily minimum temperatures recorded for the day of the year.**
- **- Extreme Min. is the minimum of all daily minimum temperatures recorded for the day of**

Figure 2.2 Annual average air temperature and precipitation conditions at the Manti, Utah meteorological site, Utah (WRCC 2006).



- Extreme Max. is the maximum of all daily maximum temperatures recorded for the day of the year.

- Ave. Max. is the average of all daily maximum temperatures recorded for the day of the year.

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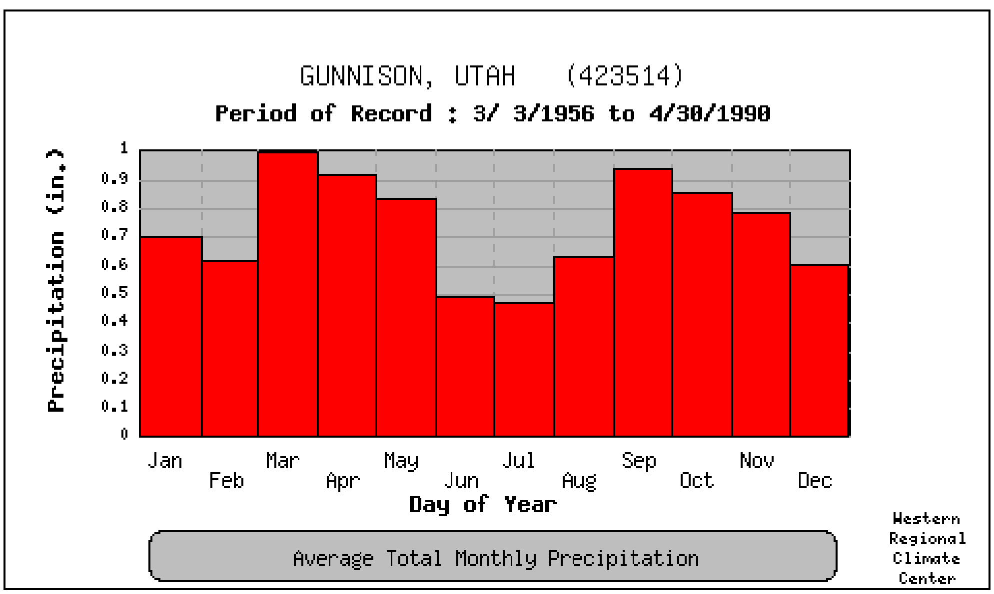


Figure 2.3 Annual average air temperature and precipitation conditions at the Gunnison, Utah meteorological site, Utah (data from WRCC, 2006).

Table 2.3 Gunnison, Utah Air Temperature Data Summary

	Monthly Average			Extreme High (°F)		Extreme Low (°F)	
	Max (°F)	Min (°F)	Average (°F)				
Annual	65.3	31.1	48.2	104	Jul 1960	-28	Feb 1989
Winter	41.8	14.6	28.2	72	Feb 1972	-28	Feb 1989
Spring	63.6	30.2	46.9	94	May 1960	-7	Mar 1964
Summer	88.7	48.4	68.5	104	Jul 1960	22	Jun 1976
Fall	66.9	31.0	48.9	96	Sep 1977	-11	Nov 1977

Winter = December, January, and February; Spring = March, April, and May; Summer = June, July, and August; Fall = September, October, and November. (WRCC data, period of record = 1956 to 1990)

Table 2.4 Gunnison, Utah Precipitation Data Summary

	Average (inches)	High (inches)		Low (inches)	
Annual	8.93	18.37	1983	5.07	1958
Winter	1.94	4.16	1978	0.36	1961
Spring	2.78	5.99	1983	1.16	1972
Summer	1.61	4.78	1984	0.32	1989
Fall	2.60	5.74	1982	0.49	1956

Winter = December, January, and February; Spring = March, April, and May; Summer = June, July, and August; Fall = September, October, and November. (WRCC data, period of record = 1956 to 1990)

2.1.2 HYDROLOGY

2.1.2.1 Surface Water Hydrology

Nine Mile Reservoir is a man-made impoundment that does not lie directly on any natural waterway. It is maintained through the artificial diversion of Six Mile Creek and the inflow of three local springs.

The reservoir is located in the San Pitch River drainage basin, bordered on the west by the San Pitch Mountains or the Gunnison Plateau with a peak elevation of 9,700 feet (3,000 meters), and on the east by the Wasatch Plateau with peak elevation of approximately 11,000 feet (3,350 meters). The San Pitch River flows north to south through the valley, entering Gunnison Reservoir immediately to the northwest of Nine Mile Reservoir near the narrow southern end of the Sanpete Valley. The San Pitch River exits Gunnison Reservoir and flows into the Sevier River, which flows generally north and west through the Gunnison Plateau, discharging eventually into a terminal basin in western Utah.

The natural watershed that directly feeds the reservoir encompasses approximately 4 square miles and includes discharge from three perennial springs. In addition to the perennial spring flow, some water is also diverted to the reservoir from Six Mile Creek. The actual contributing watershed to the reservoir, therefore, includes an additional 28,000 acres specific to the drainage of Six Mile Creek. The diversion of water from Six Mile Creek represents approximately 40% of the total inflow to the reservoir during years when the maximum volume of water designated for Nine Mile Reservoir (1,500 acre-feet) is diverted.

Six Mile Creek is located in the southern end of the Sanpete Valley and flows generally westward approximately 12 miles from its headwaters in the Wasatch Plateau toward the San Pitch River. The creek is diverted to flow into both Palisades Lake, a small reservoir located northwest of Sterling, Utah, and into Nine Mile Reservoir. The Gunnison Irrigation Company holds water rights for 1,500 acre-feet of Six Mile Creek water to augment the reservoir volume, however only 1,000 acre-feet is typically diverted. This water is diverted on the east side of Sterling, Utah and flows through an open ditch, pipe and incised channel enroute to Nine Mile Reservoir. There is no U.S. Geological Survey gage on Six Mile Creek or the diversion canal.

Diversion of water from Six Mile Creek to the reservoir generally takes place during March, April, and May though during dry years will also include October, November, and December. The maximum annual volume diverted from Six Mile Creek is 1,500 acre-feet (Rolan Beck, Gunnison Irrigation Company, personal communication with Tonya Dombrowski, 28 June 2006). Little or no water is diverted from Six Mile Creek to the reservoir during the winter months. Therefore, during the late summer and winter seasons, reservoir inflow is dominated by spring flows rather than surface water from Six Mile Creek. Springs fill the reservoir at the rate of approximately 200 acre-feet per month (Rolan Beck, Gunnison Irrigation Company, personal communication with Erica Gaddis, 16 April 2007).

The Highland Canal functions as the primary outflow to the reservoir with most water being diverted by pipeline to support irrigation downstream during summer months. The reservoir is drawn down for irrigation from June 15 to August 15 at an average rate of 50 acre-feet per day (Rolan Beck, Gunnison Irrigation Company, personal communication with Erica Gaddis, 16 April 2007). The reservoir is also designed so that emergency overflow can be diverted directly to the San Pitch River via the Spaniard Canal; however, this diversion has not been used in recent history.

2.1.2.2 Groundwater Hydrology

Groundwater within the Nine Mile Reservoir watershed can be divided into two major categories: natural groundwater and irrigation recharge. Natural groundwater refers to groundwater that is present due to geological and hydrological processes. Irrigation recharge refers to waters which are not transpired by the vegetation and percolates into the shallow aquifer as recharge.

The primary groundwater discharge areas within the Nine Mile Reservoir watershed are composed of poorly sorted Quaternary valley-fill deposits (Weiss 1994). These deposits are located within the Sanpete Valley and are adjacent to Nine Mile Reservoir. Groundwater springs surface along the mountain front and are associated with faults and valley fill. The areas east of the mountain front are composed of mostly bedrock and mass-wasting deposits. Spring runoff and summer cloudburst thunderstorms contribute to the groundwater recharge in mountain areas (Lowe et. al. 2002).

The principal valley-fill aquifer of Sanpete Valley is confined by thick, fine-grained sediments in much of the valley, located within a series of interwoven layers of clay, silt, sand, and gravel. Coarser materials generally occur along the mountain margins while finer grained material occurs in the center of the valley. On the eastern edge of the valley, near Nine Mile Reservoir, alluvial sands and gravels extend farther into the valley. In the southern end of the valley, several distinct confining layers are present and result in widely varying depth-to-water levels and head pressure in wells in close proximity. Depths to groundwater ranges from 5 feet (1.5 meters) to 200 feet (60 meters) in the vicinity of Sterling, Utah, becoming shallower with increasing proximity to the river (Snyder and Lowe 1998).

The surrounding mountains and associated alluvial fans represent the primary recharge areas for the valley-fill aquifer. Discharge areas occur predominantly along the north-south centerline of the valley. Nine Mile Reservoir and its associated springs are located in a primary recharge area of the valley floor in an area of unconsolidated valley fill. Discharge areas do not occur in association with the reservoir, and are generally located to the north of Gunnison Reservoir and the community of Manti, Utah (Snyder and Lowe 1998).

The quality of groundwater in the valley is generally high, with some areas experiencing localized nitrate contamination. Most of the groundwater in the valley is classified as IA (pristine water quality, defined as having less than 500 mg/L total dissolved solids) or II (drinking water quality, defined as having between 500 and 3,000 mg/L total dissolved solids) (Snyder and Lowe 1998).

High nitrate concentrations have been observed in groundwater at several locations in the Sanpete Valley. Wells near Moroni, Utah, located at the northern end of the valley, have shown nitrate concentrations above the state standard maximum contaminant level (MCL) of 10 mg/L. A groundwater well near Manti, Utah (approximately 6 miles northwest of the reservoir) showed nitrate concentrations of 4.5 mg/L (Snyder and Lowe 1998). The source of the nitrate contamination in these wells has not been determined. Potential sources include septic tanks, fertilizers, feedlot drainage, and natural sources such as potassium nitrates in the rock and caliche found in the Sanpete Valley.

The primary inflow source for Nine Mile Reservoir is the discharge from three perennial springs located along the eastern edge of the reservoir. Measured flow data for the springs are not available and information on spring water volumes delivered to the reservoir is anecdotal. The three springs are estimated to deliver 1 to 3, 1 to 1.5, and 0.5 cubic feet per second, respectively (spring flows identified are for springs located from south–north along the reservoir's eastern shoreline respectively). The combined inflow from these three springs is estimated at approximately 3.0 to 3.5 cfs (Rolan Beck, Gunnison Irrigation Company, personal communication with Tonya Dombrowski, 28 June 2006) and amounts to a total delivery volume of between 2,000 and 2,500 acre-feet of water annually. Peacock Spring is the main spring inflow to the reservoir and is estimated to contribute approximately 80% of the spring flow on an annual basis.

Spring flow does not appear to vary significantly from season to season, and shows little variation in flow from year to year. Some incremental decrease in spring flow was noted during the drought (discussed earlier) but it was not defined as a substantial decrease by the irrigation company (Rolan Beck, Gunnison Irrigation Company, personal communication with Tonya Dombrowski, 28 June 2006).

Topographic maps indicate the presence of additional springs within the watershed, but none are reported to deliver water to the reservoir. The groundwater quality in the area surrounding Nine Mile Reservoir, including the springs that act as the major source of water for the reservoir, are classified as Class 1A (pristine water quality, defined as having less than 500 mg/L total dissolved solids) by the Utah Geologic Survey (Lowe et al. 2002). Nitrate concentrations in the area are generally less than 3.0 mg/L although high nitrate concentrations are found in groundwater in other areas of Sanpete Valley (Lowe et al. 2002). The area that makes up the direct drainage to Nine Mile Reservoir is primarily classified as valley fill representing historic landslides and alluvial deposits, whereas bedrock makes up much of the Six Mile Creek drainage area. This area was not included in the groundwater transport modeling studies conducted for Sanpete Valley in 2002 (Lowe et al. 2002).

2.1.3 GEOLOGY AND SOILS

2.1.3.1 Geology

The Nine Mile Reservoir watershed lies within the Basin and Range-Colorado Plateau transition zone (Stokes 1986), which contains features characteristic of both the Basin and Range and Colorado Plateau Physiographic provinces. Spieker (1946) described these geologic features as follows:

The eastern margin of the plateau [Wasatch Plateau] is a sweeping stretch of barren sandstone cliffs, a southward continuation of the Book Cliffs, surmounted by higher tabular masses, in all of which the strata dip at low angles and are essentially parallel, in the general habit of the Colorado Plateaus [sic]. On the western margin the strata plunge to-ward Sanpete and Sevier Valleys in the great Wasatch monocline, at the base of which the structure is complex and a variously deformed rock succession is broken by several angular unconformities; the geologic features here are typical of the Great Basin, and their eastern limit follows in a general way the western border of the plateau.

Nine Mile Reservoir is located along the complex structural area west of the Wasatch Plateau. Local lithology is predominantly Tertiary and Mesozoic sedimentary rocks, limestone and sandstone, and minor amounts of mudstone and clay stone. The regional structure of these bedded rocks dips approximately 1 to 20 degrees to the west. The layered nature of the rocks and presence of underlying clayey rock units have created many large-scale landslide deposits during the late Pleistocene. These massive debris flow deposits cover a large part of the Six Mile Creek watershed. Sanpete Valley-fill deposits consist of unconsolidated alluvial and colluvial debris and grade into fans and alluvial/colluvial deposits along valley margins (Weiss 1994). Deposits of Arapien Shale are located adjacent to Nine Mile Reservoir and contain high amounts of gypsum and halite.

There are two major erosional processes within the Nine Mile Reservoir subwatershed: surface erosion and mass wasting. Surface erosion is the transport of soil particles from the soil surface. Common causes are meteorological and occur with overland flow caused by snowmelt, rain impact and runoff, and wind or freeze/thaw forces on steep slopes. Mass wasting includes all forms of erosion in which large masses of soil are displaced. Typical mass-wasting events may include small slumps and large debris flows, with small earth flows and rock falls present locally. The steep slopes of the Wasatch Plateau along with unstable lithology contribute to these mass-wasting events.

The watershed is ecologically transitional with the eastern half of the watershed within the Wasatch Montane Zone and Semi Arid Foothills (Omernik and Gallant 1986), characterized by the high mountains and foothills of the Wasatch Plateau. The western half of the watershed is found within the Sagebrush Basins and Slope Ecoregion with geology and soils typical of the valleys in the Great Basin.

2.1.3.2 Soils

Soil data for the Nine Mile Reservoir watershed were collected from the USDA Soil Conservation Service (USDA SCS) and the State Soil Geographic Database (STATSGO). Detailed soil maps within the Soil Survey of Sanpete Valley (USDA 1981) were also used as a reference. Soil locations and extents are detailed in Figure 2.4. Soils in valley bottoms are mostly medium to fine textured with coarser soils towards valley margins and in mountainous areas. The dominant soil types in the Nine Mile Reservoir watershed are detailed in Table 2.5. Soils in the area range in texture from fine silty to loamy skeletal and generally have medium erodibility ratings with k factors ranging from 0.24 to 0.43. The most common soil association in the Six Mile Creek watershed is the Ute-Richen-Kildor-Embargo-Cluff-Castino association. This association is a well-drained, pH neutral, extremely cobbly loam that is derived from sandstone parent material occurring on alluvial fans, hillslopes, and mountainsides. The most common soil type in the direct drainage area to Nine Mile Reservoir is the Sanpete-Rock outcrop-Amtoft. This association is a shallow, well-drained, moderately to strongly alkaline flaggy loam derived from colluvium and residuum of calcareous rocks found on hills and mountain ridges.

Table 2.5 Soil Associations and Characteristics in the Nine Mile Reservoir Watershed

Soil Name	Soil Texture	Soil Erodibility (K Factor)	Percent of Six Mile Creek Watershed	Percent of Nine Mile Reservoir Direct Drainage
Sanpete-Rock outcrop-Amtoft	Loamy skeletal	.32	5%	39%
Sanpete-Lisade-Freedom-Denmark-Arapien	Fine loamy	.37	3%	34%
Woodrow-Quaker-Linoyer-Genola	Fine silty	.43	0%	9%
Slickspots-Skumpah-Ravola-Mayfield		0	0%	2%
Lodar-Fontreen-Borvant	Loamy skeletal	.32	8%	16%
Rogert family-Myton family-Kamack-Castino family	Loamy skeletal	.32	12%	0%
Ute-Richens-Kildor-Embargo-Cluff-Castino	Fine	.28	47%	0%
Rock outcrop-Mower-Lundy-Lizzant-Hamtah-Agassiz	Loamy skeletal	.24	25%	0%
Sanpete-Rock outcrop-Amtoft	Loamy skeletal	.32	5%	39%

A more detailed soil analysis was conducted for the area immediately surrounding Nine Mile Reservoir and the diversion from Six Mile Creek. This analysis used the updated SSURGO dataset provided by the NRCS in order to assess the natural impact of alkaline soils in the immediate vicinity. The Genola loam soil just south of Nine Mile Reservoir has a particularly high pH value (10.1). In addition, other soils surrounding the reservoir are also alkaline with pH values that range from 8 to 10. These soils include Arapien, Woodrow, and Poganeab soils and it is reasonable to assume that they extend underneath Nine Mile Reservoir and naturally contribute to the alkalinity of the reservoir water. Approximately 70% of the land area in the direct drainage to Nine Mile Reservoir is covered in soils that have a representative pH value greater than 8.0. (See Figure 3.5)

2.1.4 PLANTS, ANIMALS, AND FISHERIES

2.1.4.1 Upland Plant Communities

Plant community composition in the Nine Mile Reservoir watershed is determined by a combination of climate and geologic factors including elevation, exposure, soil type and depth, and moisture or precipitation. Elevations over 8,000 feet (2,500 meters) near the headwaters of Six Mile Creek are forested with ponderosa pine (*Pinus ponderosa*), spruce (*Picea* spp.), Douglas fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), and patches of quaking aspen (*Populus tremuloides*) in the overstory. Understory species include serviceberry (*Amelanchier* spp.), alder-leaf mountain-mahogany (*Cercocarpus montanus*) and Gambel's oak (*Quercus gambelii*).

The pinyon-juniper community is dominant at elevations from 6,000 to 8,000 feet (1,828–2,500 meters). The overstory consists of pinyon pine (*Pinus edulis*), Utah juniper (*Juniperus osteosperma*), and Gambel's oak. Dominant understory species include big sagebrush (*Artemisia tridentata*), rabbitbrush (*Chrysothamnus* spp.), squaw apple (*Peraphyllum ramosissimum*) and serviceberry (*Amelanchier* spp.). cheatgrass (*Bromus tectorum*), Indian ricegrass (*Achnatherum hymenoides*), winterfat (*Krascheninnikovia lanata*), and wiregrass (*Juncus* spp.) (Welsh 2003).

The dominant plant species at elevations below 6,000 feet (1,828 meters) include low-growing rabbitbrush, shadscale (*Atriplex* spp.), various sagebrushes (*Artemisia* spp.), greasewood (*Sarcobatus* spp.) and a variety of grasses including saltgrass (*Distichlis spicata*), wiregrass, Indian ricegrass, and others.

Two substantial wildfires have occurred recently within the upper Simile Creek drainage. In 1992, 794 acres burned during a prescribed burn and in 2004 approximately 4,794 acres burned due to lightning strikes. The USFS allowed the fire to burn naturally except where it threatened to impact Sterling, Utah. Approximately 555 acres were common to both fires.

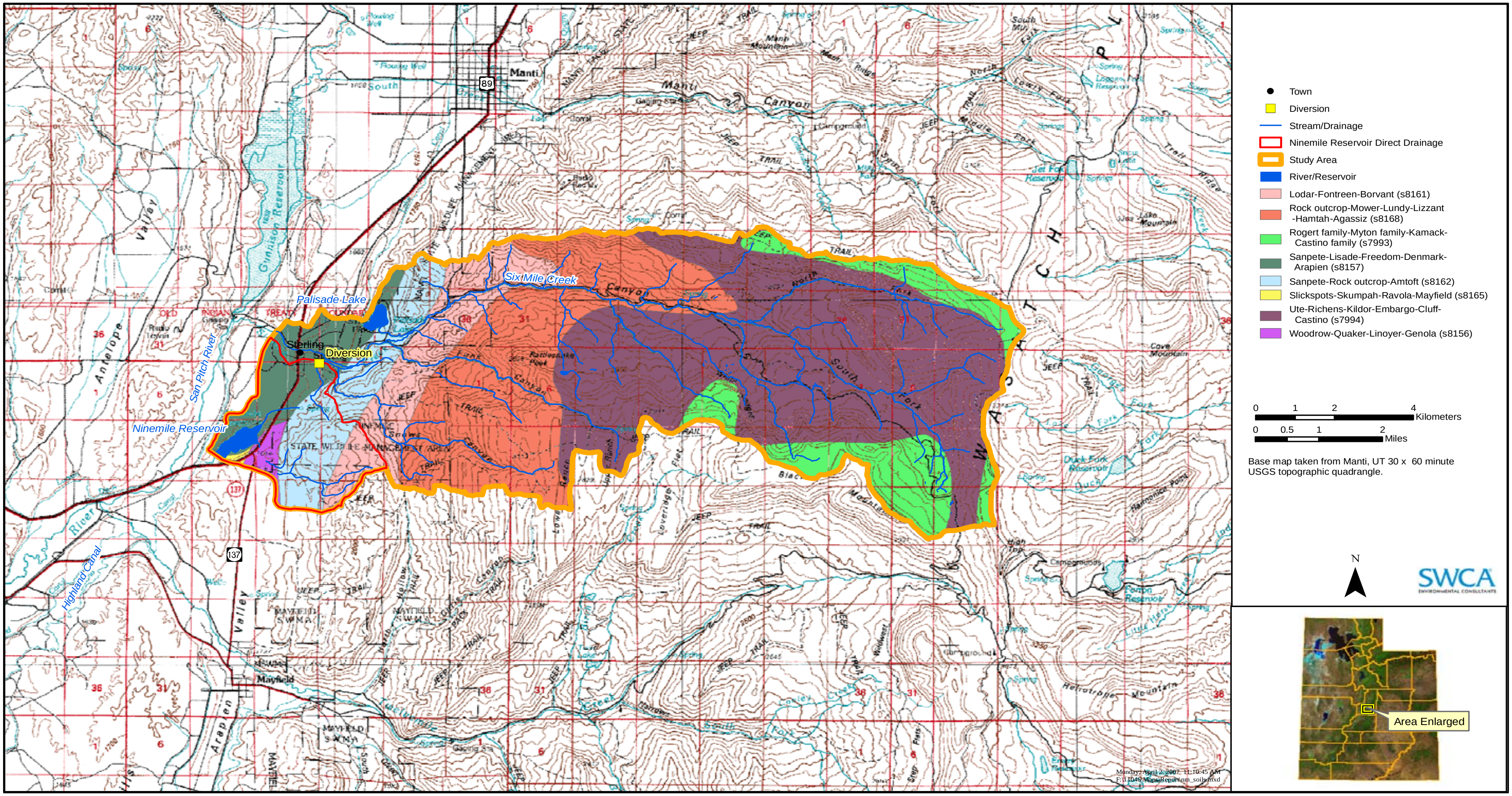


Figure 2.4 Soils map of Nine Mile Reservoir watershed

2.1.4.2 Riparian Plant Community

Riparian areas constitute only a small portion of the overall watershed area, but are ecologically important in terms of plant diversity, wildlife habitat, and erosion control along waterways. Local riparian communities are characterized by yellow willow (*Salix lutea*), whiplash willow (*Salix exigua*), wild rose (*Rosa woodsii*), wiregrass (*Juncus* spp.) and Nebraska sedge (*Carex nebrascensis*). Other associated riparian plant species include Douglas sedge (*Carex douglasii*), veronica (*Veronica* spp.), golden currant (*Ribes aureum*), redtop (*Agrostis gigantea*), clover (*Trifolium* spp.), trefoil (*Lotus* spp.), and narrowleaf cottonwood (*Populus angustifolia*) (USFS 2005 and Welsh 2003).

2.1.5 WILDLIFE

Wildlife found in the Nine Mile Reservoir watershed are indicative of pinyon-juniper woodlands, mountain brush communities, willow/riparian, and rock habitats at mid-elevations in Utah. Game species include mule deer, Rocky Mountain elk, and wild turkey. Other mammals in the area include bobcat, coyote, red squirrel, and various smaller rodents. Several bat species can be observed at night flying along the roadway adjacent to Six Mile Creek. Other nocturnal wildlife species include great-horned owls, striped skunks, and raccoons.

The most common birds found during the spring and summer months include western scrub jay, mourning dove, American robin, yellow warbler, spotted towhee, chipping sparrow, vesper sparrow, red-winged blackbird, western meadowlark, and less often, yellow-breasted chat, and broad-tailed hummingbird. Turkey vultures and common ravens are also seen frequently.

2.1.5.1 Fisheries

Nine Mile Reservoir supports stocked fish species that include rainbow trout, tiger trout, and a brown trout/brook trout hybrid. Six Mile Creek supports a population of wild cutthroat trout, while brook trout and rainbow trout have been stocked in some ponds and reservoirs in the Six Mile Creek drainage (email communication, Utah Division of Wildlife Resources, Central Region). No documented fish kills have occurred in the reservoir (UDWQ 2007).

2.1.5.2 Special Designations

The Utah Division of Wildlife Resources (UDWR) has records of occurrence for Bonneville cutthroat trout and Nine Mile pyrg (spring snail) within the project area. In addition, in the vicinity, there are records of occurrence for bald eagle, Colorado River cutthroat trout, and leatherside chub. All of the aforementioned species are included in the Utah Sensitive Species List (Utah Division of Wildlife Resources 2006).

2.2 CULTURAL CHARACTERISTICS

Primary cultural influences in the Sanpete Valley have included the Fremont-Sevier agriculturalists (present until around A.D. 1300), the San Pitch Tribe and Ute Tribe, and the Mormon settlers. The latter came to the Manti area in the fall of 1849, choosing to settle in the area because of the warm spring nearby, good agricultural land and soils, and the nearby limestone quarries (Utah History Online 2006).

Sterling, Utah, located on U-89 midway between Manti and Gunnison, is the closest population center to Nine Mile Reservoir. The town, settled in 1873, is reported to have been named for the "sterling" qualities of its people, and has been known by various names including Pettyville, Pettytown, Leesburg, and Buncetown (Utah History Online 2006).

2.2.1 LAND USE AND OWNERSHIP

The watershed is predominantly forested, both public and private. The largest landowner is the USFS which manages 69.8% of the watershed area as part of the Manti-LaSal National Forest. Private land consists of 15.6%, and Utah State land consists of 14.6%. The private land is used for agricultural purposes including crops and grazing.

The town of Sterling is located inside of the watershed. Residential areas comprise less than one percent of the total watershed area. Historically, land use within the watershed was primarily forestry and agriculture. Numerous poultry farms are located in the area and livestock grazing is also a key activity.

Geographic information system (GIS) coverages, satellite imagery, aerial photographs, and other cartographic resources were employed in the preparation of this document to determine accurate land use (Figure 2.5, Table 2.7) and ownership (Figure 2.6, Table 2.6) values for the Nine Mile Reservoir Watershed on a subwatershed basis.

Table 2.6 Land Ownership within the Nine Mile Watershed Study Area

	Six Mile Creek Watershed		Nine Mile Reservoir Direct Drainage		Total Study Area
	Area (acres)	Percentage of Total Land	Area (acres)	Percentage of Total Land	Percentage of Total Land
US forest service (USFS)	19,696.1	77.2%	0.0	0.0%	69.8%
Private	2,785.6	10.9%	1,622.0	59.5%	15.6%
State wildlife reserve/management	2,827.2	11.1%	764.3	28.0%	12.7%
State trust land	92.7	0.4%	221.4	8.1%	1.1%
Water	51.2	0.2%	118.8	4.4%	0.6%
State parks and recreation	48.2	0.2%	0.0	0.0%	0.2%
TOTAL	25,501.0	100.0%	2,726.5	100.0%	100.0%

Table 2.7 Land Use within the Nine Mile Watershed Study Area

	Six Mile Creek Watershed		Nine Mile Reservoir Direct Drainage		Total Study Area
	Area (acres)	**Percentage of Total Land**	**Area (acres)**	**Percentage of Total Land**	**Percentage of Total Land**
Evergreen forest	12,236.7	48.0%	540.9	19.8%	45.3%
Shrub/scrub	5,353.9	21.0%	1,442.1	52.9%	24.1%
Deciduous forest	3,717.8	14.6%	0.0	0.0%	13.2%
Mixed forest	1,584.1	6.2%	0.0	0.0%	5.6%
Developed uses	259.8	1.0%	118.5	4.3%	1.3%
Grassland/herbaceous	1,097.9	4.3%	14.4	0.5%	3.9%
Barren land (rock/sand/clay)	778.6	3.1%	31.5	1.2%	2.9%
Pasture/hay	343.6	1.3%	318.0	11.7%	2.3%
Open water	82.7	0.3%	196.9	7.2%	1.0%
Cultivated crops	29.1	0.1%	64.1	2.4%	0.3%
Woody wetlands	16.7	0.1%	0.0	0.0%	0.1%
TOTAL	25,500.9	100.0%	2,726.4	100.0%	100.0%

2.2.2 POPULATION

The town of Sterling is the only population center within the watershed boundary and is located approximately 1.5 miles northeast of the Nine Mile Reservoir. Total population figures for Sterling average approximately 251 individuals (US Census Bureau 2007). In addition to the local resident population, tourism and recreational opportunities have created some transient (county and non-county resident) visitor use on Nine Mile Reservoir and within National Forest areas. Total population figures for the Nine Mile Reservoir watershed area are estimated at approximately 300 individuals, the majority of which (200) live in the town of Sterling and adjacent unincorporated areas.

Nearby communities include Mayfield, approximately 5 miles to the south (population 425); Manti, the county seat, approximately 6 miles to the northeast (population 3,185); Gunnison, approximately 9 miles west-southwest (population 2,700); Centerfield, approximately 10 miles to the southwest (population 1,051); Fayette, approximately 12 miles to the west-northwest (population 204); Ephraim, approximately 14 miles to the northeast (population 4,977); and Redmond, approximately 18 miles to the southwest (population 790). Populations listed are those projected for 2005 by the 2000 US Census figures (US Census Bureau 2007)

Many of these communities experienced substantial growth during the 1990s. An average of 40% increase in population occurred in those communities located within a 10-mile radius of Sterling. Similar growth is projected to occur within the county over the next decade, with an associated conversion of agricultural land use to rural residential land use (City Data 2006).

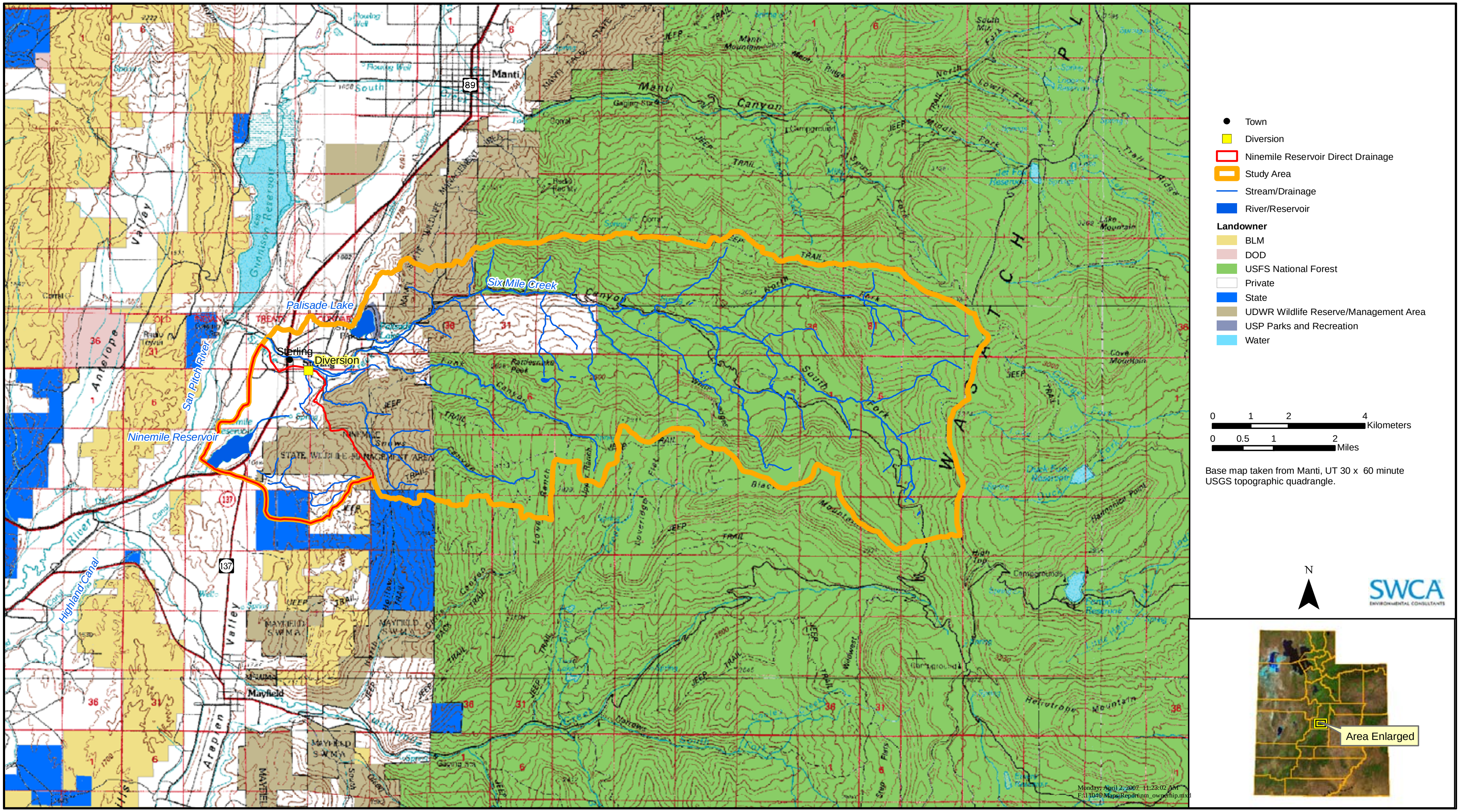


Figure 2.5 Land ownership and populated areas map for Nine Mile Reservoir watershed

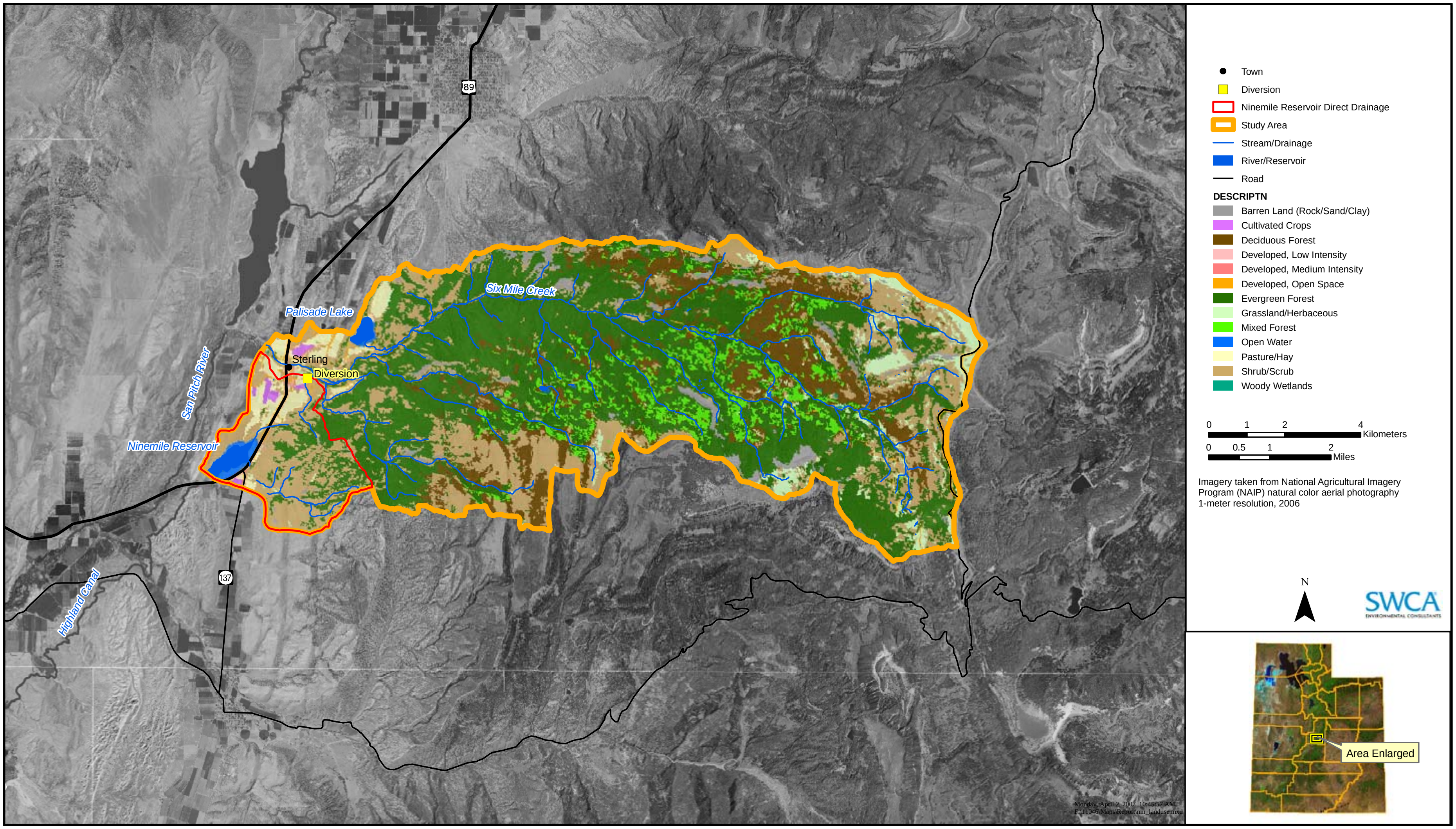


Figure 2.6 Land use map for Nine Mile Reservoir watershed

2.2.3 HISTORY AND ECONOMICS

Since settlement, Sanpete County's economy has been based almost exclusively on agriculture. Cattle dominated in the early years following settlement, but only a few large dairy farms still operate in the region.

Sheep dominated the local economy from the 1880s through the 1920s, and the county held a prominent role in world markets for a time. During the 1920s, Sanpete County's sheep herds were the largest in Utah (RMRS 2005).

Snow College, a two-year college located in Ephraim, also plays an important role in the local economy. (Populations listed are those projected for 2005 by the 2000 (US Census Bureau 2007).

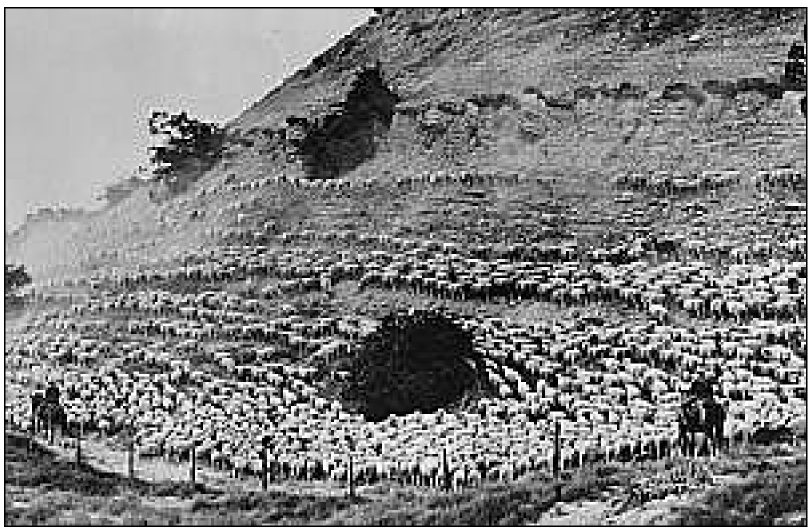


Figure 2.7 Sheep being moved from high-elevation summer pasture to winter range in the desert, Sanpete County, circa 1930 (AITC 2005).

During this period, high animal densities and lack of understanding of appropriate land management practices led to severe overgrazing in the high-elevation watersheds on the Wasatch Plateau in central Utah. This condition resulted in catastrophic flooding and mudflows through adjacent communities. Manti, Utah was inundated by damaging flood waters, as were other local communities, and affected citizens petitioned the Federal government to establish a forest reserve in 1902. The Manti National Forest was established by the Transfer Act of 1905, and the Great Basin Station, a forerunner of the Intermountain Forest and Range Experiment Station, was created in 1911 to study the influence of rangeland vegetation on erosion and floods. Terracing along the hillsides on the east side of Sanpete Valley to reduce runoff and encourage infiltration of snowmelt and rainfall, is still visible within the watershed and adjacent areas. Practices developed and studies conducted at the Great Basin Experiment Station have enhanced and updated many of the interpretations and guidelines for the management of high-elevation watersheds throughout the intermountain west (RMRS 2005).

Revegetation following overgrazing has resulted in changes to the plant communities in high-elevation watersheds, and current vegetation composition is significantly different than the original condition. New plant communities have reached thresholds where the vegetative composition appears to be climate driven. Many of the higher elevation areas however, still remain in unsatisfactory condition and experience routine active erosion events (RMRS 2005).

Sheep remain an important element in the state's and Sanpete County's agricultural economy, but the high densities that occurred in the 1920s are no longer present. Turkeys, originally grown only casually, became a necessary and major cooperative as a result of the 1930s Great Depression which led to a severe decline in wool prices. Today, poultry is the dominant agricultural product of the county, which ranks among the top ten turkey-producing counties in the United States (Utah History Online 2006).

The current economy of the region is based primarily on agricultural industries, generally centered on livestock and poultry farming, with increasing input from tourism and recreation on National Forest lands and wilderness areas. Livestock is grazed on public and private land within the watershed and adjacent to the reservoir.

2.2.4 Recreational Uses of Nine Mile Reservoir

2.2.4.1 Boating and Related Activities

Although the reservoir is privately owned, access to the reservoir is unlimited. Access to the Nine Mile Reservoir is via US-89 south of Sterling at the U-137 junction. The major recreation activity for the reservoir is fishing from boats. This activity is limited during the later part of the summer season as the reservoir levels drop to low levels.

2.2.4.2 Fishing, Hunting, and Wildlife Observation

The primary recreational use of the reservoir is fishing, although usage has been reported as light. The Division of Wildlife Resources stocks the reservoir annually with either 15,000 catchable rainbow trout or 3,000 catchable and 25,000 advanced fingerling rainbow trout. The reservoir was drained in 1981 to raise the dam to a new elevation. The reservoir was also chemically treated in 1959 and 1970 by the DWR to reduce rough fish levels.

2.2.4.3 Camping

There are no camping facilities located near the reservoir. Camping facilities are located in the watershed at the Palisade State Park, located east of Sterling. There is also a USFS campground located in Manti Canyon.

2.2.5 Public Involvement

Prior to beginning the TMDL planning process for Nine Mile Reservoir, the San Pitch River Watershed Stewardship Committee was established to inform the San Pitch River Watershed Water Quality Management Plan, completed in 2003 (UDWQ 2003).

During the initiation of the Subbasin Assessment process, a structured citizen involvement program was established and included participation by members of the San Pitch River Watershed Stewardship Committee as an advisory group to the TMDL process. This program was established so that the community could provide direction and leadership in developing and implementing this plan. The watershed advisory group membership includes local representatives from all major sectors of the local community as follows:

- Agricultural interests
- Gunnison Irrigation Company
- Sterling/Six Mile Irrigation Company
- Citizens at large
- City of Sterling
- Local development representative
- Environmental concerns
- Sporting or recreational interests
- Timber interests
- Sanpete County Commissioners
- USFS Manti-LaSal National Forest
- US Bureau of Land Management
- Utah Division of Wildlife Resources

3 WATER QUALITY CONCERNS AND STATUS

3.1 WATER QUALITY LIMITED WATER BODIES

As stated in the opening sections of this document, the main purpose of the CWA is to improve and protect water quality through restoration and maintenance of the physical, chemical and biological integrity of the nation's waterways. Under section 303(d) of the CWA, each state must submit a list to the EPA identifying waters throughout the state that are not achieving state water quality standards in spite of the application of technology-based controls in NPDES permits. The waters identified on the 303(d) list are known as water quality limited. Nine Mile Reservoir was identified under section 303(d) of the CWA in 2006, as water quality limited due to low dissolved oxygen and excess phosphorus loading to the reservoir from the surrounding watershed.

3.2 BENEFICIAL USE CLASSIFICATIONS FOR NINE MILE RESERVOIR

The State of Utah has designated the beneficial uses of Nine Mile Reservoir to be secondary contact recreation (classification 2B), cold water game fish and their associated food chain (3A), and agricultural water supply (4). The cold water game fish designated use (3A) was identified as non-supporting on the State of Utah 2006 303(d) list. Secondary contact recreation and agricultural water supply designated uses were reported as being fully supported on this same list.

Recreation classifications are for water bodies that are suitable or are intended to be made suitable for primary and secondary contact recreation; this includes fishing for consumption. Secondary contact recreation refers to uses where intimate human contact and ingestion of water is expected to occur to a lesser degree such as fishing, boating and wading.

Waters designated and supportive of cold water game fish and associated food chain use are required to exhibit appropriate levels of dissolved oxygen, temperature, pH, ammonia, and turbidity. Nine Mile Reservoir is not listed as impaired for temperature or pH. The analysis presented in Section 3.5 of this assessment indicates that exceedances of water quality criteria are associated with natural conditions.

Waters designated as agricultural water supply (including irrigation water and livestock watering) are required to be suitable for the irrigation of crops or as drinking water for livestock. Waters designated for agricultural water supply are required to meet general surface water quality criteria for toxic materials. These waters are also required to meet narrative criteria related to sediment and excessive nutrients.

3.3 APPLICABLE WATER QUALITY STANDARDS

Water quality standards under the CWA consist of three main components: designated beneficial uses, water quality criteria that are established to protect designated beneficial uses, and antidegradation policies and procedures.

Water quality criteria can be either numeric limits for individual pollutants and conditions, or narrative descriptions of desired conditions. Table 3.1 summarizes the applicable State of Utah water quality criteria and lists specific citations where the full code language can be found.

Table 3.1 Water Quality Numeric Criteria and Pollution Indicator Values Specific to Nine Mile Reservoir Found in Utah State Code RS 317-2-14

Parameter and Designated Beneficial Use	Criterion	Utah State Code Table	Comments
Bacteria			
2B	<206 *E coli* organisms per 100 ml as a 30 day geometric mean; AND maximum less than 940 *E coli* organisms per 100 ml.	Table 2.14.1	
3A	N/A		
4	N/A		
Dissolved Oxygen (DO)			
2B	N/A		
3A	No less than 6.5 mg/L (30-day average), 9.5 early life stages/5.0 all life stages (7-day average), 8.0 early life stages/4.0 all life stages (1-day average).	Table 2.14.2	Footnote #2: These limits are not applicable to lower water levels in deep impoundments.
4	N/A		
Biological Oxygen Demand (BOD)			
2B	No greater than 5 mg/L	Table 2.14.1	
3A	No greater than 5 mg/L	Table 2.14.2	
4	No greater than 5 mg/L	Table 2.14.1	

Table 3.1 Water Quality Numeric Criteria and Pollution Indicator Values Specific to Nine Mile Reservoir found in Utah State Code RS 317-2-14, continued

Nutrients–Ammonia as N			
2B	N/A		
3A	mg/L as N (Acute) = 0.275/(1+10 E7.204-pH)) + (39.0/(1+10 EpH-7.204))	Table 2.14.2	
4	N/A		
Nutrients - Nitrate as N			
2B	No greater than 4 mg/L	Table 2.14.1	Footnote #5: Investigations shall be conducted to develop more information where these pollution indicator levels are exceeded.
3A	No greater than 4 mg/L	Table 2.14.2	
4	N/A		
Nutrients - Total Phosphate as P			
2B	No greater than 0.05 mg/L	Table 2.14.1	Footnote #5: Investigations shall be conducted to develop more information where these pollution indicator levels are exceeded.
3A	No greater than 0.05 mg/L	Table 2.14.2	Footnote #12: Total phosphorus as P (mg/L) limit for lakes and reservoirs shall be 0.025 mg/L.
4	N/A		
pH			
2B	No less than 6.5 AND no greater than 9.0 pH units	Table 2.14.1	
3A	No less than 6.5 AND no greater than 9.0 pH units	Table 2.14.2	
4	No less than 6.5 AND no greater than 9.0 pH units	Table 2.14.1	

Table 3.1 Water Quality Numeric Criteria and Pollution Indicator Values Specific to Nine Mile Reservoir found in Utah State Code RS 317-2-14, continued

Turbidity			
2B	No greater than 10 NTU increase	Table 2.14.1	
3A	No greater than 10 NTU increase	Table 2.14.2	
4	N/A		
Total Dissolved Gas			
2B	N/A		
3A	Not to exceed 110% of saturation.	Table 2.14.2	
4	N/A		
Total Dissolved Solids			
2B	N/A		
3A	N/A		
4	< 1,200 mg/L (irrigation), < 2,000 (stock watering)	Table 2.14.1	
Temperature			
2B	N/A		Footnote #3: The temperature standard shall be at background where it can be shown that natural or un-alterable conditions prevent its attainment. In such cases rulemaking will be undertaken to modify the standard accordingly.
3A	No greater than 20°C, No greater than 2°C change	Table 2.14.2	
4	N/A		

3.4 SUMMARY AND ANALYSIS OF EXISTING WATER QUALITY DATA

3.4.1 WATER QUALITY DATA COVERAGE

The available dataset covers a range of water years and a variety of physical, chemical and biological water quality constituents. To better evaluate the existing dataset, available data were divided into several subsets to allow identification of temporal, spatial, and constituent coverage and completeness in both a general and a specific fashion. Identified water quality concerns in the Nine Mile Reservoir system were used as the primary basis for data collection and delineation. Therefore, while additional data exist (such as metal and pesticide concentration information), they have not been included in this data summary.

3.4.1.1 Temporal Coverage

Data available for this TMDL process has been divided into the following three categories: 1982 to 1992 (historic), 1993 to 1998 (recent), and 1999 to present (current). Data collected prior to 1982 will be categorized as "legacy data" and its use will be restricted to trend analysis within the study.

Monitoring data included in this data summary are available from the mid-1970s through mid-2006, covering a wide range of water years and flow scenarios. Data to be used for this TMDL process have been restricted to data from 1999 to 2006. As detailed in Table 3.4, some monitoring locations have consistent data throughout this time period, while others were collected intermittently or for a single year or event.

Data collected prior to 1982 were assumed not to be representative of current conditions in the watersheds and were therefore excluded from the water quality assessment database. In addition, these data may have inherent liabilities associated with outdated sampling or analysis methods resulting in a condition where direct comparison cannot be made between old and current measurements. Additionally, flow, diversion, and land use management within the watershed has changed considerably in some cases since the early 1980s and transport and delivery relationships derived from early data are not likely to be representative of current conditions.

It should be noted that much of the data from the early 1990s through 2004 were collected under moderate to extreme drought conditions. Physical water quality characteristics such as temperature and dissolved oxygen concentrations measured during these water years will be representative of critical watershed conditions as drought generally exacerbates such conditions within the watershed. The most current data have been used for assessment of criteria or threshold exceedance, pollutant transport and processing, and pollutant loading analyses.

Current data were the primary source of information used to determine the support level of designated beneficial uses, and will be employed to help define appropriate endpoints or thresholds (if applicable) for the Nine Mile Reservoir system.

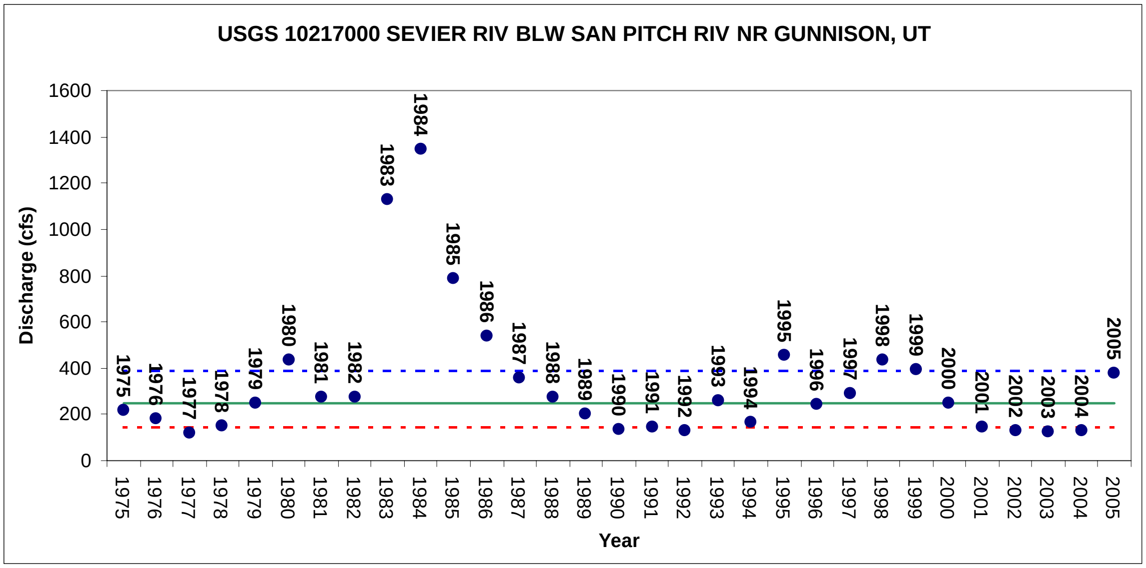


Figure 3.1 Annual discharge volumes for the Sevier River below the San Pitch River near Gunnison, Utah from 1975 through 2005 (USGS Gage #10217000).

3.4.1.2 Hydrological Coverage

Data were collected over a wide range of hydrological conditions. As gaged flows were not available for the Nine Mile watershed, nearby drainages with continuous gage information were used as a surrogate measure of relative flow volume and intensity. Annual total flow volumes calculated from gaged flows in the Sevier River below the San Pitch River inflow near Gunnison, Utah (USGS gage # 10217000) are displayed in Figure 3.1.

Based on the assumption that ungaged flows in the Nine Mile Reservoir watershed are similar in trend volume and flow-to-gaged flows in nearby drainages (Sevier River below the San Pitch River inflow near Gunnison, Utah) early water years (1982–1992) represent low–average to above average water years (average flow at 10217000 gage was 145% of the 30-year average for that time period). More recent water years (1993 through 1998) represent primarily low to average flow conditions (average flow at 10217000 gage was 93% of the 30-year average for that time period). Current water years (1999 through 2006) are generally well below average with the exception of 2005 which had a moderately high-water year at the gage location (average flow at 10217000 gage was 66% of the 30-year average for that time period). Water years 2002 through 2004 represent years with less than 40% of the 30-year average flow values at the gage location.

Annual flow volumes and ranking relative to the 30-year average for USGS gage #10217000 are displayed in Table 3.2.

Current water quality data collected in the Nine Mile Reservoir watershed are representative of a wide range of flow values and describe both very low (2002 and 2004, 39% of the 30-year average flow volume measured at the Sevier River below the San Pitch River inflow near Gunnison, Utah) and average (1999 and 2005, 118% and 114% of the 30-year average flow volume measured at the Sevier River below the San Pitch River inflow near Gunnison, Utah) hydrologic conditions. Therefore, data collected between 1999 and 2006 are expected to be representative of high flow and low flow (critical conditions) within the watershed.

Data collection is somewhat weighted toward the late spring to late fall months, with fewer winter data points in most datasets.

Assuming that ungaged flows in the Nine Mile Reservoir watershed are similar in trend volume and flow-to-gaged flows in nearby drainages (Sevier River below the San Pitch River inflow near Gunnison, Utah), seasonal data collection are assumed to cover the range of high (spring runoff in May and June) and low (July, August and September) seasonal flows over the course of a year.

On both a water year and on a seasonal basis, available data collection times were compared with representative precipitation indices for high, average, and low water years. Data collection generally occurred over the critical range of flow and precipitation regimes, indicating (to the extent possible) that data coverage is representative of an adequate variety of flow and precipitation events.

3.4.1.3 Spatial Coverage

Surface water quality data are available for Nine Mile Reservoir and its associated watershed (Table 3.3). Sites represent inflow, in-reservoir, and outflow conditions. While all sites do not share the same level of data density, cumulatively, these monitoring sites represent good spatial coverage of the reservoir system.

While the sites identified provide good inflow and in-reservoir information, the outflow data available is from two limited sample suites collected in the summer of 2006 and may not be representative of all flow and/or water quality conditions.

3.4.2 STATISTICAL OVERVIEW

Primary information sources for water quality data used in this analysis included the EPA STORET website, Utah Division of Water Quality (UDWQ), Utah Department of Water Resources (UDWR), Utah Geological Survey (UGS), Utah Department of Natural Resources (UDNR), US Geological Survey (USGS), US Forest Service (USFS), US Bureau of Land Management (BLM), Natural Resources Conservation Service (NRCS), Gunnison Irrigation Company, Sanpete County, state and local soil and water conservation services, irrigation districts, and their associated databases, and others.

Groundwater flow and volume information is general in nature and available almost exclusively from USGS, UGS and county studies and reports. Climate information was obtained from WRCC and SNOTEL sites.

The UDWQ, USGS, EPA, and others have been monitoring water quality at a number of sites in the Nine Mile watershed since the mid 1970s. Locations for which water quality information is available include in-reservoir monitoring sites and Six Mile Creek, as well as other sites such as groundwater wells.

Five intensive water quality monitoring sites were identified as appropriate to the TMDL efforts, one site on Six Mile Creek upstream of the reservoir, two in-reservoir sites (Mid-reservoir Site and Dam Site), one location on the inflow to the reservoir, and the canal receiving the outflow from the reservoir. In addition, SWCA collected data from springs flowing into the Nine Mile Reservoir. A listing of all sites used in this analysis and a summary of the raw data available is presented in Tables 3.3 and 3.4.

Table 3.2 Annual Flow Volumes and Ranking Relative to the 30-year Average for the Sevier River at USGS gage #10217000

Water Year	Flow (cfs)	Percent of 30-year Average Flow
1970	315	94%
1971	238	71%
1972	165	49%
1973	349	104%
1974	298	89%
1975	217	65%
1976	181	54%
1977	117	35%
1978	148	44%
1979	249	74%
1980	435	130%
1981	276	82%
1982	277	83%
1983	1,130	338%
1984	1,346	403%
1985	787	235%
1986	539	161%
1987	356	106%
1988	275	82%
1989	204	61%
1990	135	41%
1991	147	44%
1992	132	39%
1993	261	78%
1994	164	49%
1995	458	137%
1996	246	73%
1997	292	87%
1998	438	131%
1999	395	118%
2000	246	74%
2001	147	44%
2002	130	39%
2003	126	38%
2004	132	39%
2005	381	114%
30-year average	334	100%

Table 3.3 Water Quality Monitoring Sites for the Nine Mile Reservoir Watershed

Org Name	Station ID	Station Name
UDEQ	5943240	NINE MILE RES AB DAM 01 (Dam Site)
SWCA	None	NINE MILE RES AT DAM (Dam Site)
SWCA	None	NINE MILE RES INFLOW
UDEQ	5943260	NINE MILE RES INFLOW
UDEQ	5943250	NINE MILE RES MID-RESERVOIR 02 (Mid-reservoir Site)
SWCA	None	NINE MILE RESERVOIR OUTFLOW
UDEQ	4946190	HIGHLAND CNL AT US89 BL NINE MILE RES
	5943430	HIGHLAND CNL BL NINE MILE RES
UDEQ	4946360	SIX MILE CK AB CNFL / SAN PITCH R NW OF STERLING
SWCA	None	SIX MILE CREEK AT DIVERSION TO NINE MILE RES
SWCA	None	SPRING #1 DIRECT INFLOW TO NINE MILE RESERVOIR
SWCA	None	SPRING #2 DIRECT INFLOW TO NINE MILE RESERVOIR
SWCA	None	SPRING #3 DIRECT INFLOW TO NINE MILE RESERVOIR

In-reservoir monitoring by UDEQ includes both grab (instantaneous) samples and depth-integrated profile data for some parameters. Sites with Station ID #s are intensive monitoring sites managed by UDEQ-DWQ.

In total, over 5,000 data points were identified and assessed for Nine Mile Reservoir, covering the time period from 1979 through 2006.

Early monitoring consisted primarily of field parameters, nutrients, oxygen demand, dissolved ions and metals analyses, and groundwater studies. This work was followed in the 1990s with pesticide analyses, more in-depth nutrient and organic carbon studies, bacterial analysis, and some trophic status-related parameters.

Recent and current data contain a variety of field parameters, nutrient, sediment, dissolved ion, and metals analyses (Table 3.4). Quantitative data were not available for stream channel stability, riparian corridor health, or stream morphology for the reservoir or tributary sites. Biological data are primarily speciation of algal populations.

Water quality constituents determined to be critical to the assessment of designated beneficial use support status are represented in Table 3.4. These constituents include those related to low dissolved oxygen, excess nutrients, eutrophication, and water quality criteria specific to beneficial uses in Nine Mile reservoir as defined in Table 3.1.

Table 3.4 Summary of Data Available for Nine Mile Reservoir and Watershed

Characteristic	N	Start	Stop	Max	Min	Mean	Median
5943260 NINE MILE RES INFLOW							
Alkalinity, Carbonate as CaCO3	1	6/12/90	6/12/90	272	272	272	272
Dissolved oxygen (DO)	22	6/12/90	8/18/06	9.9	5.4	7.22	7.84
Dissolved solids	17	6/12/90	8/18/06	740	224	605	668
Flow	25	5/27/92	1/26/06	8.0	0.0	1.96	1.5
Nitrogen, ammonia as N	18	6/12/90	11/17/05	0.09	Nondetect	0.07	0.02
Nitrogen, Kjeldahl	4	6/12/90	8/18/06	Nondetect	Nondetect	Nondetect	Nondetect
Nitrogen, Nitrite (NO2) + Nitrate (NO3) as N	18	5/27/92	8/18/06	6.730	Nondetect	4.37	6.25
pH	23	6/12/90	8/18/06	8.7	7.6	8.1	8.06
Phosphorus as P total	19	5/27/92	8/18/06	0.274	Nondetect	0.047	0.01
Phosphorus as P dissolved	17	6/12/90	8/18/06	0.03	Nondetect	0.01	0.005
Specific conductance	22	6/12/90	8/18/06	1234	394	897.25	1023
Temperature, water	22	6/12/90	8/18/06	26.4	12.4	17.3	17.0
Total suspended solids (TSS)	17	6/12/90	11/17/05	269	4	33.2	8
Turbidity	2	6/12/90	8/18/06	1627.4	1.3	814.35	814
Volatile solids	10	5/27/92	5/28/02	31.0	2.0	4.78	2.0
4946360 SIX MILE CK AB CNFL / SAN PITCH R NW OF STERLING							
Alkalinity, Carbonate as CaCO3	33	5/6/97	5/6/97	338	205	244.9	244
Dissolved oxygen (DO)	34	9/2/76	8/18/06	11.6	6.8	9.04	9.1
Dissolved solids	36	9/2/76	8/18/06	890	218	352	290
Flow	32	7/26/77	6/20/02	100.0	0.0	14.2	4.0
Nitrogen, ammonia as N	30	10/13/76	6/20/02	0.10	Nondetect	0.03	0.10
Nitrogen, Kjeldahl	8	9/2/76	8/18/06	2.50	0.20	0.70	0.40
Nitrogen, Nitrite (NO2) + Nitrate (NO3) as N	28	4/2/96	8/18/06	2.800	0.140	0.512	0.330
pH	73	9/2/76	8/18/06	9.1	8.0	8.5	8.5
Phosphorus as P total	32	9/2/76	8/18/06	0.301	Nondetect	0.068	0.049
Phosphorus as P dissolved	26	4/2/96	8/18/06	0.097	Nondetect	0.005	0.013
Specific conductance	64	9/2/76	8/18/06	1490	308	599	512
Temperature, water	36	9/2/76	8/18/06	23.0	1.4	10.8	10.2
Total suspended solids (TSS)	34	9/2/76	6/20/02	829	Nondetect	110.65	54
Turbidity	33	9/2/76	8/18/06	223.0	0.4	51.6	15.0
5943240 NINE MILE RES AB DAM 01							
Alkalinity, Carbonate as CaCO3	23	5/21/81	9/8/05	373	221	288	290
Chlorophyll *a*, uncorrected for pheophytin	21	6/12/90	9/8/05	26.1	Nondetect	4.27	1.8
Dissolved oxygen (DO)	138	6/12/90	8/18/06	15.6	0.3	8.9	9.7

Table 3.4 Summary of Data Available for Nine Mile Reservoir and Watershed

Characteristic	N	Start	Stop	Max	Min	Mean	Median
Dissolved solids	23	5/21/81	8/18/06	934	336	550	530
Nitrogen, ammonia as N	56	5/21/81	9/8/05	0.52	Nondetect	0.09	0.0625
Nitrogen, Kjeldahl	11	5/21/81	7/19/06	1.38	0.19	0.53	0.40
Nitrogen, Nitrite (NO2) + Nitrate (NO3) as N	52	5/27/92	7/19/06	2.130	Nondetect	0.28	0.175
pH	155	6/12/90	8/18/06	10.1	7.8	9.0	9.0
Phosphorus as P total	56	5/21/81	7/19/06	0.586	Nondetect	0.036	0.01
Phosphorus as P dissolved	52	9/7/90	7/19/06	0.31	Nondetect	0.02	0.01
Secchi disk depth	22	6/12/90	9/8/05	8.3	0.2	2.9	2.5
Specific conductance	147	5/21/81	8/18/06	1422	422	824	801
Temperature, water	138	6/12/90	8/18/06	25.8	14.1	19.85	19.8
Total suspended solids (TSS)	24	5/21/81	9/8/05	54	Nondetect	8.13	3
Turbidity	23	5/21/81	8/18/06	24.0	0.5	4.56	2.9
Volatile solids	12	5/27/92	8/8/02	11.0	Nondetect	3.25	2.0
5943250 NINE MILE RES MID-RESERVOIR 02							
Alkalinity, Carbonate as CaCO3	2	6/12/90	9/7/90	297	259	278	278
Chlorophyll *a*, uncorrected for pheophytin	17	6/12/90	9/8/05	43.2	Nondetect	5.6	1.8
Dissolved oxygen (DO)	102	6/12/90	8/18/06	15.2	0.6	9.43	10.0
Dissolved solids	2	6/12/90	7/19/06	586	494	540	540
Nitrogen, ammonia as N	35	5/21/81	9/8/05	0.35	Nondetect	0.09	0.064
Nitrogen, Kjeldahl	6	5/21/81	7/19/06	1.26	0.15	0.58	0.55
Nitrogen, Nitrite (NO2) + Nitrate (NO3) as N	31	5/27/92	7/19/06	1.180	Nondetect	0.29	0.155
pH	104	6/12/90	8/18/06	9.9	7.9	9.0	9.0
Phosphorus as P total	34	5/21/81	7/19/06	0.282	Nondetect	0.032	0.01
Phosphorus as P dissolved	32	9/7/90	7/19/06	0.021	Nondetect	0.008	0.0075
Secchi disk depth	18	6/12/90	9/8/05	6.2	0.3	3.0	3.1
Specific conductance	102	6/12/90	8/18/06	1372	56	796	797
Temperature, water	102	6/12/90	8/18/06	24.4	13.8	20.0	19.9
Total suspended solids (TSS)	16	6/12/90	9/8/05	32	Nondetect	5.28	2
Turbidity	2	6/12/90	8/18/06	5.0	2.0	3.5	3.5
Volatile solids	9	6/28/94	5/28/02	12.0	Nondetect	3.88	8.0
Springs Discharging to the Reservoir							
Dissolved oxygen (DO)	5	7/19/06	8/18/06	7.2		2.72	6.8
Dissolved solids	6	7/19/06	8/18/06	1300	321	711	630
Flow	5	7/19/06	8/18/06	0.024	0	0.005	--
Nitrogen, Kjeldahl Total	3	7/19/06	7/19/06	0.21	0.07	0.12	0.09

Table 3.4 Summary of Data Available for Nine Mile Reservoir and Watershed

Characteristic	N	Start	Stop	Max	Min	Mean	Median
Nitrogen, Nitrite (NO2) + Nitrate (NO3) as N	3	7/19/06	7/19/06	6.700	0.025	2.26	--
pH	5	7/19/06	8/18/06	8.4	7.4	8.1	8.3
Phosphorus as P total	3	7/19/06	7/19/06	0.016	0.006	0.011	0.012
Phosphorus as P dissolved	3	7/19/06	7/19/06	0.014	0.005	0.009	0.007
Specific conductance	5	7/19/06	8/18/06	2180	672	1352	1126
Temperature, water	5	7/19/06	8/18/06	22.3	12.0	18.1	21.6
Turbidity	5	7/19/06	8/18/06	2636.0	484.5	624.1	1560.3

3.4.2.1 Analytical Methods

Data collected and assessed for the Nine Mile Reservoir TMDL consisted of samples evaluated by four primary categories of analytical methodology: APHA, USEPA, Utah DWQ generic, and Utah DWQ field methods.

3.4.2.1.1 APHA Methods.

These methods refer to the American Public Health Association (APHA 1992). APHA-approved methods specific to the available database for Nine Mile Reservoir TMDL include analytical procedures for measuring alkalinity, chemical oxygen demand, chloride, chlorophyll, dissolved solids, fecal coliform bacteria, fecal streptococcus group bacteria, fixed solids, pH, total coliform bacteria, total organic carbon, total suspended solids, volatile solids, and others not pertinent to this TMDL effort.

3.4.2.1.2 USEPA Methods

These methods refer to methods approved by the US Environmental Protection Agency (EPA 1983). USEPA-approved methods specific to the available database for Nine Mile Reservoir TMDL include analytical procedures for measuring ammonia, biochemical oxygen demand, chloride, nitrate + nitrite, phosphorus, specific conductance, total suspended solids, turbidity, volatile solids, and others not pertinent to this TMDL effort.

3.4.2.1.3 Utah DWQ Generic Methods (generic method and generic method 2)

These refer to the Utah Division of Water Quality (DWQ) methods entered in the STORET database.

UTAH DWQ generic methods (generic method and generic method 2) specific to the available database for Nine Mile Reservoir TMDL include measurements of alkalinity, ammonia, biochemical oxygen demand, chemical oxygen demand, chloride, chlorophyll *a*, nitrate, nitrate + nitrite, pH, orthophosphate, phosphorus, specific conductance, total Kjeldahl nitrogen, total organic carbon turbidity, and others not pertinent to this TMDL effort.

Due to the fact that the data in this analysis category were collected, reviewed, and submitted to the STORET database by DWQ, it was assumed that all sampling protocols and analytical methods employed were carried out in a fashion approved by DWQ and contained and attained a DWQ approved level of quality assurance and quality control.

3.4.2.1.4 Utah DWQ Field Measures

These refer to the Utah Division of Water Quality (DWQ), *Quality Assurance/Quality Control Manual (1996)*. Utah DWQ field measures approved methods specific to the available database for Nine Mile Reservoir TMDL include analytical procedures for measuring chlorine, dissolved oxygen, flow, pH, salinity, Secchi depth, specific conductance, and temperature (air and water).

3.4.2.2 Quality Assurance and Quality Control

The data were assessed to ensure that all data points included in the TMDL process met an appropriate level of quality. Basic statistical analyses were used to characterize the range and quality of data. Statistical parameters assessed included the number of data points, determination of mean, median, maximum and minimum values, assessment of variance, and an analysis of seasonality. The completeness of the dataset was also evaluated in a spatial, temporal, and parameter-specific fashion, and critical data gaps were identified. Further evaluation is discussed in the following sections.

3.4.2.2.1 Treatment of Nondetects

Many of the data points (10% of total data points) collected in this dataset are concentration values identified as “below detection limits”, “greater than quantitation limits”, or “too numerous to count.” For the purpose of analyzing the data, standard methods were used to statistically interpret these values. This was accomplished by assigning a numeric value of one-half of the detection limit (in the case of concentrations identified as below detection limits) or a value that represents 1.5 times the quantitation limit (in the case of concentrations identified as greater than quantitation limits).

Detection limits were reported in the STORET database for most data points and provided a specific nondetect value for most data. If data point specific detection limits were not provided, detection limits were applied based on specific analytical methods. In some cases, UDWQ monitoring data did not identify a specific analytical method; instead identifying the analytical procedure as “generic method” or “generic method 2.” Arne Hultquist of the UDWQ Monitoring Section, provided method numbers and detection limits for nondetect data for which no detection limits were reported in the STORET database.

In the case of bacteriological data, where numerous dilutions are used to determine the total counts, an upper quantitation limit cannot be identified directly from the method summary. In cases where total concentrations were listed as being greater than the quantitation limits, or too numerous to count, a value of 1.5 times the highest quantified concentration was substituted. This provided a numeric value that allowed statistical analyses to be performed. Such a substitution most likely represents an underestimation of the total bacteria count present. However, as the quantitation limits for the analysis of total coliform and fecal coliform bacteria are rarely lower than the state criteria for contact recreation, the recommended substitution is not expected to result in a situation where risk to recreationists is unidentified (no false negatives). Furthermore, it is not likely to result in a situation where bacterial loading is grossly overestimated within the watershed.

3.4.2.2.2 Treatment of Errors

An initial assessment of the data was performed to identify transcription and other errors such as inappropriate values (e.g., a pH value of 129), inaccurate sample information (e.g., units of mg/L for specific conductivity data), and errors in physical information (e.g., incorrect county or latitude information for a known sample site). A small number of such errors were identified and corrective action was taken as outlined below.

A number of sample sites included data points of zero (0). It was not immediately obvious what these values represented. Possible interpretations include the following:

- Mis-entry of an analytical Nondetect
- An error in a spread sheet used to enter data to STORET, or an error within the STORET database that did not allow display of appropriate decimal places and resulted in values of less than one being displayed and recorded as 0
- Direct transcription errors
- A combination of the above and other unknown errors

Because of this uncertainty, zero values were removed from all datasets, with the exception of measured or estimated flow, water, and air temperature measurements where a zero value is possible. The total number of zero values removed from the Nine Mile Reservoir dataset was 31 (0.7% of the water quality dataset). Zero values occurred in this dataset for total suspended solids (19 points) and volatile solids (12 points).

The available data for site # 5943250 NINE MILE RES MID-RESERVOIR were erroneously identified as being located in Uintah County. Site numbers and latitude/longitude information were checked and found to be accurate thus all listings of Uintah County were changed to Sanpete County for this site.

3.4.2.2.3 Treatment of Outliers

To identify a final dataset that was representative of water quality conditions within the Nine Mile Reservoir watershed, a threshold of plus or minus three standard deviations from the mean was applied to the available datasets. This resulted in the removal of approximately 27 data points from the Nine Mile Reservoir dataset (less than 1% of the dataset). This mechanism for identifying non-representative data is a standard method used by DWQ in assessing water bodies and has been found to be the most objective method for excluding potentially erroneous or nonrepresentative data. Outliers excluded from the dataset include three total phosphorus values in Nine Mile Reservoir and one total phosphorus value in Six Mile Creek. One chlorophyll *a* value in Nine Mile Reservoir was also excluded.

3.4.2.2.4 Analytical Implications of Outlier Exclusion and Nondetect Treatment

The exclusion of outliers results in the mean total phosphorus concentration in the reservoir to be reduced from above the 0.025 mg/L threshold to below the threshold (Table 3.5). Exclusion of historic data further reduces mean concentrations. Exclusion of historic data also reduces the mean total phosphorus concentration in Six Mile Creek from above the 0.05 mg/L threshold for streams to well below the threshold. It is important to note that more than half of the total phosphorus data points available for the in-reservoir monitoring locations, the reservoir inflow, and Six Mile Creek, are reported as nondetect. As a result, the median value for all of these sites, regardless of outlier exclusion, is calculated at half the detection limit averaging to 0.005 mg/L. Similar reductions in chlorophyll *a* are observed when outliers and historic data are excluded from mean calculations.

Table 3.5 Change in Total Phosphorus Mean Concentration (mg/L) Through Exclusion of Outliers and Historic Data

Site	Entire Dataset	Exclusion of Outliers	Current Data Only (1999–2006)	
	Mean	Mean	Mean	Median
Nine Mile Reservoir inflow	0.040	0.029	0.033	0.005
Nine Mile Reservoir outflow	0.063	0.063	0.083	0.083
Nine Mile Reservoir at dam	0.032	0.023	0.009	0.005
Nine Mile Reservoir at mid-reservoir	0.029	0.022	0.023	0.005
SIX MILE CK AB CNFL / SAN PITCH R NW OF STERLING	0.059	0.053	0.017	0.005
Springs discharging to the reservoir	0.011	0.011	0.011	---

Table 3.6 Change in Mean chlorophyll *a* Concentration (µg/L) Through Exclusion of Outliers and Historic Data

Site	Entire Dataset	Exclusion of Outliers	Current Data Only (1999– 2006)	
	Mean	Mean	Mean	Median
Reservoir at dam	5.3	5.3	3.8	1
Mid-reservoir	6.1	4.0	2.5	0.7

Since the exclusion of outliers has such a critical impact on the support status assessment of Nine Mile Reservoir, potential causes for the outliers in the current dataset were explored. Of the three total phosphorus outliers in Nine Mile Reservoir, only one occurs during the current period of 1999 to 2006. This value of 0.586 was collected by UDEQ on August 9, 2000. The other two data points were collected on September 9, 1992 at different depths. The chlorophyll *a* outlier was collected by UDEQ on August 9, 1994. These outliers appear to be associated with low water levels in the reservoir, measured as maximum depth at dam at the time data was collected (Figures 3.2 and 3.3). Since no conservation pool has been established for Nine Mile Reservoir, when the reservoir is drawn down its minimum level it no longer can support fish due to a lack of water. When the reservoir still maintains a small pool of water, it can quickly become stagnant and warm thereby reducing viable habitat for a cold water fishery and promoting in-reservoir algal growth. Watershed level nutrient reductions would not have a substantial improvement on this condition which is primarily a function of reservoir level management and water rights. For this reason, exclusion of outlier values is justified regardless of whether outliers represent erroneous data or result from low reservoir volume.

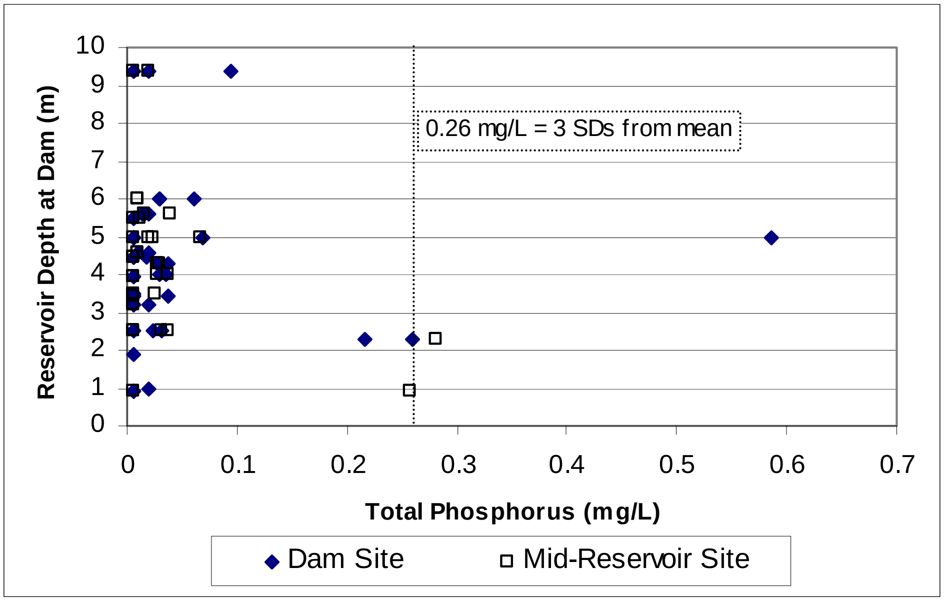


Figure 3.2 Total phosphorus related to reservoir level indicating that the low reservoir level may explain outliers.

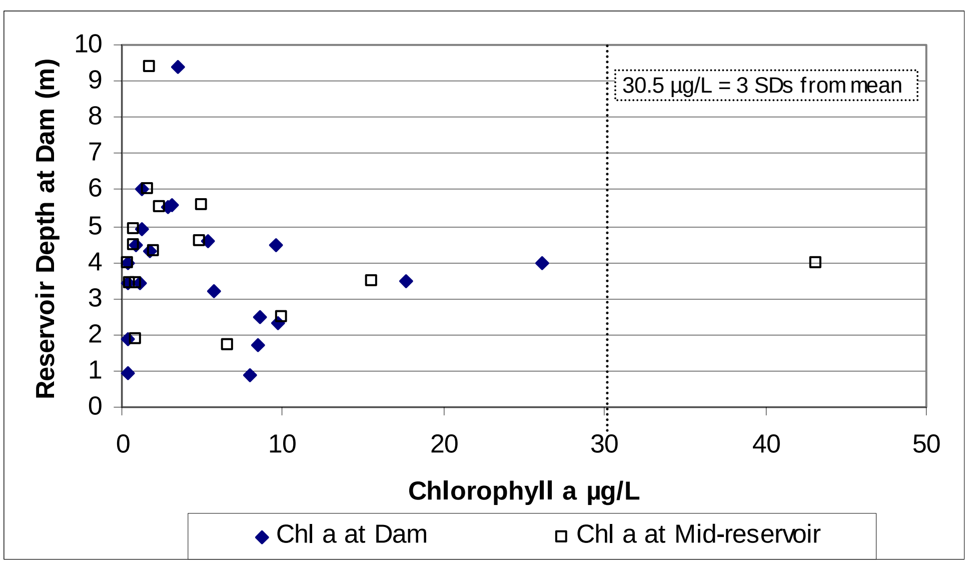


Figure 3.3 Chlorophyll *a* related to reservoir level indicating that the low reservoir level may explain outliers.

3.5 ASSESSMENT OF BENEFICIAL USE SUPPORT

3.5.1 KEY INDICATORS OF SUPPORT

3.5.1.1 Low Dissolved Oxygen

Dissolved oxygen (DO) is important to the health and viability of fish and other aquatic life. Aquatic life depends on high concentrations of dissolved oxygen (from 6–8 mg/L or greater). Low dissolved oxygen (concentrations below 5 mg/L) can result in stress, reduced resistance to other environmental stressors, and even death at very low levels (less than 2 mg/L).

In addition to direct effects on aquatic life, low dissolved oxygen concentrations can lead to changes in water and sediment chemistry that can influence the concentration and mobility of nutrients and toxins—e.g., changes in phosphorus, ammonia, and mercury levels in the water column. Low dissolved oxygen at the sediment-water interface can result in substantial release of sorbed phosphorus in the water column, which in turn can lead to increased algal growth and decreased dissolved oxygen concentrations. Anoxic conditions, combined with available organic matter, can result in higher rates of methyl mercury production. Methyl mercury represents a significantly greater threat for bioconcentration and accumulation than elemental or mineralized mercury compounds. Finally, increased water column concentrations of ammonia can result from the chemical changes caused by anoxic conditions. Elevated ammonia levels threaten the health of aquatic life forms and, at extreme concentrations, can result in death.

Low dissolved oxygen often results from high nutrient, organic, or algal loading to a surface water system. Nutrients promote algae growth, which in turn consumes oxygen from the water column during periods when respiration is the dominant process (generally at night). In addition, dying algae in lakes and reservoirs settle to the bottom of the water body and decompose; aerobic decomposition of the dead algae and other detritus (nonliving organic material) depletes the oxygen supply in the overlying water and sediment. In systems where suspended solids are primarily organic in origin, low dissolved oxygen levels may be correlated with sediment inputs as well.

Dissolved oxygen concentrations are also reduced by pollutants that require oxygen in oxidation processes. Biochemical oxygen demand (BOD) is a measure of the dissolved oxygen required to oxidize material (usually organic), whether the material is naturally occurring, the result of increased natural material, or contained in municipal, agricultural, or industrial wastes. Some of the delivered organic material is algae and some is detritus. Both of these organic matter components produce a certain amount of BOD. A substantial organic load may be delivered to the reservoir during high volume and high velocity spring flow events.

3.5.1.2 pH

A key indicator of acidity or alkalinity of a system is pH, as measured by the hydrogen ion activity in the water. A pH value of 7.0 is neutral, with values from 0 to 7 indicating acidic water and those from 7 to 14 indicating alkaline water. Extremely acidic or alkaline waters can be toxic to aquatic life. Even at less extreme levels, acidic or alkaline conditions can cause chemical shifts in a system; acidic conditions can release metallic compounds from sediments while alkaline conditions can increase ammonia toxicity and release sorbed phosphorus.

Both living and dead (decomposing) algae can have minor effects in the pH of the water due to the release of various acid and base compounds during respiration and photosynthesis.

3.5.1.3 Temperature

Appropriate temperature is crucial to water quality and support of aquatic habitat. Temperature determines whether or not a water body can support warm or cold water aquatic species. High water temperatures can be harmful to fish at all life stages, especially when high temperatures combine with other habitat limitations such as low dissolved oxygen or poor food supply. As a stressor to adult fish, elevated temperatures can lower body weight, reduce oxygen exchange, and diminish reproductive capacity. Extremely high temperatures can result in death if they persist for an extended length of time. Juvenile fish are more sensitive to temperature variations and duration than adult fish and tend to experience negative impacts at a lower threshold value than the adults.

Acceptable temperature ranges vary for different species of fish; warm water species adapt better to rising water temperatures than cold water fish. Protective criteria have been established to serve the needs of important cold and warm water species of aquatic life. The temperature criteria are usually built around a maximum allowable value that relates to critical life-stage requirements.

3.5.1.4 Nutrients

General concerns associated with excessive nutrient concentrations relate to both direct and indirect effects. Direct effects include nuisance algae and periphyton growth. Indirect effects include low dissolved oxygen, increased methyl mercury production, elevated pH, cyanotoxins from cyanobacteria (blue-green algae) production, trihalomethane production in drinking water systems, and maintenance issues associated with domestic water supplies.

Nuisance aquatic growth, both algae (phytoplankton, or water column algae, and periphyton, or attached algae) and rooted plants (macrophytes) can adversely affect both aquatic life and recreational water uses. Algal blooms occur where nutrient concentrations (nitrogen and phosphorus) are sufficient to encourage excessive growth. Levels necessary for growth may occur at concentrations well below the identified water quality thresholds and criteria. Available nutrient concentrations, flow rates, velocities, water temperatures, and sunlight penetration in the water column are all factors that influence algae (and macrophyte) growth. When conditions are appropriate and nutrient concentrations exceed the quantities needed to support algal growth, excessive blooms may develop. Commonly, these blooms appear as extensive layers or algal mats on the surface of the water.

Algal blooms often create objectionable odors in water used for recreation and can produce intense coloration of both the water and shorelines. Water bodies demonstrating sufficient nutrient concentrations to cause excessive algal growth are said to be eutrophic. Algae is not always damaging to water quality, however. The extent of the effect is dependent on both the type(s) of algae present and the size, extent, and timing of the bloom. In many systems, algae provide a critical food source for many aquatic insects, which in turn serve as food for fish.

Algae growth also has indirect effects on water quality. When algae die, they sink slowly through the water column, eventually collecting on the bottom sediments. As the algae decompose, the biochemical processes that occur remove oxygen from the surrounding water. Because most of the decomposition occurs within the lower levels of the water column, dissolved oxygen concentrations near the bottom of lakes and reservoirs can be substantially depleted by a large algal bloom. Low dissolved oxygen in these areas can lead to decreased fish habitat and even fish kills if there are not other areas of water with sufficient dissolved oxygen available where the fish can take refuge.

Both nitrogen and phosphorus represent nutrients that can contribute to eutrophication. Either nutrient may be the limiting factor for algal growth depending on algal species. In systems where cyanobacteria (blue-green algae) are the dominant population, nitrogen is not a limiting agent based on this ability to fix nitrogen. Therefore, these organisms can grow where low nitrogen concentrations may inhibit the growth of other algal species (Sharpley et al. 1995 and 1984; Tiessen 1995). These systems are therefore phosphorus limited. Freshwater systems are usually phosphorus limited, however there is a large body of literature concerning the impact of the nitrogen-to-phosphorus ratio (N:P) in freshwater systems. Typically N:P ratios less than 10 suggest a nitrogen limited system, whereas higher ratios suggest that nitrogen and phosphorus are either co-limiting or that the system is phosphorus limited. However, the cut off for an N:P ratio below which nitrogen is likely the limiting agent ranges from 7 to 15 (EPA 2000).

The nitrogen-to-phosphorus ratio in Nine Mile Reservoir averages 23.4 at the dam and 22.1 at mid-reservoir. The ratios range from a low of 0.05 to a high of 142. However, these estimates are based on a very narrow dataset because there are very few dates for which total phosphorus and total nitrogen data are available. Many data points do not come from the recent or current dataset (defined as 1992 and later). These N:P data suggest that Nine Mile Reservoir is most likely phosphorus limited, although it has previously been classified as a nitrogen limited system by the State of Utah (UDWQ 2007).

Table 3.7 Nitrogen to Phosphorus Ratios in Nine Mile Reservoir

	N:P Mid-reservoir	N:P Dam
5/21/1981	23.3	24.0
6/12/1990	30.7	22.4
9/7/1990	15.2	19.2
5/27/1992	32.6	5.3
9/9/1992	11.0	9.5
6/28/1994	3.0	4.0
8/9/1994	2.8	2.9
6/19/1996	15.0	8.3
9/3/1996	18.0	18.4
6/30/1998	45.2	24.9
9/10/1998	24.0	27.5
6/14/2000	10.0	10.0
8/9/2000	3.6	0.5
5/28/2002	44.8	46.0
8/8/2002	--	11.8
6/9/2004	50.0	33.6
7/20/2004	10.0	10.0
8/10/2004	--	13.0
9/14/2004	--	142.0
6/15/2005	11.2	48.5
8/11/2005	47.0	22.3
9/8/2005	22.0	10.0
Overall Average	**22.1**	**23.36**
Overall Maximum	**50**	**142**
Overall Minimum	**2.79**	**0.54**
Current Average (1999–2006)	**24.8**	**31.6**

Excess nutrient loading causes water quality problems due to the direct effect of high phosphorus concentrations on excess algal growth within the water column, combined with the direct effect of the algal life cycle on dissolved oxygen and pH within aquatic systems. As total phosphorus (TP) includes both dissolved and particulate-bound phosphorus, it represents the phosphorus that is currently available for growth as well as that which has the potential to become available over time.

Consideration of flow is important in the evaluation of nutrients and phytoplankton, periphyton, and rooted macrophyte concentrations. In a riverine system, flow transports phytoplankton and nutrients from upstream to downstream in an advective or dispersive transport mode. In other words, the riverine system is a dynamic system in which nutrients are being continually cycled as the water moves downstream. The flow regimen is important in determining the result of this combination of component concentrations. High flows can flush dissolved constituents like nutrients downstream. High flows can also scour periphyton and rooted macrophytes, reducing their concentrations considerably in-stream and concentrating them in the receiving water body. Finally, when high flows scour sediments and sediment is moved downstream, sediment-bound nutrient concentrations also increase as buried sediment is exposed.

High total phosphorus concentrations can lead to increases in the rate of algal growth and in overall productivity, up to the saturation point. The increased algal biomass production and transport increases biological oxygen demand and decreases dissolved oxygen levels. Reservoir systems that experience low flow-through rates during the growing season can experience conditions that are optimal to algae growth and decomposition.

A separate consideration is the difference between algae concentrations and the rate of algal growth. Algal concentrations are determined by the availability of nutrients on a continuing basis, the availability of adequate light, and the presence of flows (velocities) that will permit continued growth without losses due to flushing (of phytoplankton), sloughing (of attached algae or periphyton), or mechanical breakage and scouring (of rooted macrophytes). In quiescent systems like Nine Mile Reservoir, algal concentrations during the summer season are dependent on nutrient availability, and only if nutrient concentrations have been depleted by algal uptake does the growth rate approach zero and phytoplankton begin to die.

In streams and rivers, the nutrients also cycle between the water, sediment, living organisms, and detritus; this is called nutrient spiraling. Generally, high velocities occur often enough to scour attached and rooted vegetation and to keep concentrations of aquatic vegetation low. Under low velocities, however, attached and rooted vegetation may increase to noticeable levels. As long as nutrients continue to be available and flows are inadequate to cause losses of algae mass, the algae will continue to grow and may reach levels that cause algal mats on the bottom or at the surface. This is often the case in shallow lakes or ponds or in pools found in intermittent streams. However, the presence of algal mats or attached algae does not necessarily indicate an excess of nutrients.

Many sources and conditions in the environment add nutrients to water bodies. Phosphorus can be present as a constituent of certain rock types (e.g., siliceous igneous rock) and in the mineral apatite. Nitrogen is a major component of the atmosphere and enters biological systems through nitrogen fixation and rock weatherization.

The environment itself can also be a factor in the phosphorus levels occurring within a region, since the climate, pH of natural waters, and the presence of other substances that may adsorb or release phosphorus (Hedley et al. 1995) can all potentially affect phosphorus levels. In addition, soil chemistry, redox potential, and nutrient ratios affect the cycling of nitrogen in natural systems. There are also anthropogenic (man-made) nutrient sources. Applied fertilizers in farming, landscaping and pasture management, manure treatment, the duration and density of livestock grazing, the creation of artificial waterways and water levels through irrigation and water management practices, as well as the presence of sewage and septic waste (treated and untreated) in the surface, subsurface, and groundwater of a region often represent significant contributions to the phosphorus concentration in an area. Natural sources of nutrients include the indigenous wildlife and waterfowl that use the watershed. While these populations are relatively stable throughout much of the year, substantial increases in some populations are observed with spring and fall migration patterns.

Nitrogen occurs in the environment in a variety of sources and forms. It can be present as a mineral constituent of certain rock types, as a result of the decomposition of plant and other organic material, in rainfall (as a component of agricultural or urban/suburban runoff), and as a constituent in septic discharges.

It is likely that both physical and chemical processes impact the transport and availability of phosphorus and nitrogen in the Nine Mile Reservoir watershed. Physical processes (wind and water movement) dominate in the transport of phosphorus contained within or adsorbed into sediment and particulates. Chemical processes (i.e., changes in water chemistry such as dissolved oxygen, pH levels, or redox) dominate in the transport of dissolved phosphorus to the system and in the transformation of phosphorus from one form or state (i.e., free or adsorbed) to another, within both the transport pathway and the water column.

Table 3.8 Summary of Current Dissolved Oxygen Data (1999–2006) in Nine Mile Reservoir Watershed.

Site Name	N	Mean	Maximum	Minimum	Standard Deviation
Inflow	17	7.53	9.16	5.85	1.09
Dam Site	135	8.84	15.58	0.28	3.66
Mid-reservoir Site	98	9.82	15.24	1.37	2.75

3.5.2 Direct Exceedance of Numeric Criteria and/or Threshold Values

3.5.2.1 Dissolved Oxygen

Current data collected in Nine Mile Reservoir (1999-2006) indicate that dissolved oxygen concentrations are generally quite high with mean concentrations ranging from 8.8 to 9.9 mg/L. Minimum dissolved oxygen concentrations range from 0.28 to 1.37 mg/L and are limited to the sediment-water interface at the bottom of the reservoir.

As fish and most other aquatic life species are mobile and can relocate to areas of suitable habitat in the event of a localized criteria exceedance, the State of Utah has defined the support status of game fish populations relative to the percentage of the total water column experiencing depressed dissolved oxygen concentrations. A water body's dissolved oxygen concentration is defined to have a non-support status for cold water game fish when less than 25% of the water column depth exhibits dissolved oxygen concentrations of 4.0 mg/L or greater. If 25 to 50% of the water column depth exhibits dissolved oxygen concentrations of 4.0 mg/L or greater, the water body is defined as having a partial-support status. Where greater than 50% of the water column depth exhibits dissolved oxygen concentrations of 4.0 mg/L or greater, a full-support status has been defined. These criteria were assessed on average for each month in the algal growth season (May-October) for which water column data were available.

Table 3.9 Percent of Total Samples in Exceedance of Dissolved Oxygen Criteria (>4 mg/L)

Site Name	2000	2001	2002	2004	2005	2006	Mean
Inflow	0%		0%	0%	0%	0%	0%
Dam Site	20%		0%	8%	13%	26%	14%
Mid-reservoir Site	8%		0%	11%	5%	0%	5%

There have been no observed exceedances of the percent water column criteria for dissolved oxygen established by the State of Utah. All dissolved oxygen water column exceedances have affected less than 25% of the water column. At the dam, low dissolved oxygen (less than 4.0 mg/L) was experienced in 0% of the water column on average in May and September, 12% of the water column in June, 9% of the water column in July, and 6% of the water column in August (Table 3.10). The greatest incidence of dissolved oxygen exceedance observed at this site involved 19% of the water column and occurred in August of 2006. On average, low dissolved oxygen (less than 4.0 mg/L) was experienced in 0% of the water column at the Mid-reservoir Site in May, 5% of the water column in June, 0% of the water column in July, 0% of the water column in August and 0% of the water column in September (Table 3.10). The greatest incidence of dissolved oxygen exceedance observed at this site involved 13% of the water column and occurred in June of 2006.

Table 3.10 Nine Mile Exceedance – DO Less Than 4.0 mg/L (% of Water Column)

Site Name	Month	2000	2001	2002	2003	2004	2005	2006	AVERAGE
Dam Site	May	--	--	0%	--	--	--	--	0%
	June	14%	--	--	--	8%	13%	15%	12%
	July	--	--	--	--	0%	18%		9%
	Aug	--	--	--	--	0%	0%	19%	6%
	Sept	--	--	--	--	--	0%	--	0%
Mid-reservoir Site	May	--	--	0%	--	--	--	--	0%
	June	0%	--	--	--	6%	0%	13%	5%
	July	--	--	--	--	0%	0%	--	0%
	Aug	--	--	--	--	--	0%	0%	0%
	Sep	--	--	--	--	--	0%	--	0%

3.5.2.2 Dissolved Oxygen Saturation

Dissolved oxygen saturation data are reported in the STORET database for both surface measurements and water column measurements. The water quality criterion for dissolved gases established by the State of Utah is 110% of saturation due to the stress supersaturated water can cause for fish. Values greater than 110% are considered to be exceedances of state water quality criteria. The measurements collected at depth and reported in the STORET database had not been corrected for hydrostatic pressure. The amount of gas that can be dissolved in water is influenced by atmospheric pressure, hydrostatic pressure, and water temperature. When oxygen is produced below 1 to 4 meters of depth, more of it can remain dissolved because of hydrostatic pressure leading to oxygen accumulation frequently exceeding several hundred percent supersaturation relative to the pressure at the surface of the reservoir (Wetzel 2001).

In order to correct dissolved oxygen saturation for data collected below 1 meter of depth in Nine Mile Reservoir, the following equation was applied (Wetzel 2001):

$$P_z = P_0 + 0.0967z$$

Where P_z is the actual pressure at a given depth, P_0 is the atmospheric pressure at the surface of the reservoir, and z is the depth of the measurement in meters. Because atmospheric pressure data was not available for each data collection date, a mean average atmospheric pressure of 0.866 atmospheres was assumed. Resulting calculated dissolved oxygen saturation values closely matched data collected at the surface of the reservoir and reported in STORET. Measured atmospheric pressure is commonly observed near this value for Manti, Utah close to Nine Mile Reservoir. Correction of dissolved oxygen saturation data at depths greater than 1 meter greatly affects the summary statistics for this parameter. Using the raw data reported by STORET, the mean dissolved oxygen saturation value in the reservoir (at depths greater than 1 meter) ranged from 111% at the dam site to 123% at the Mid-reservoir Site. The mean corrected dissolved oxygen saturation data are significantly lower, ranging from 88% at the dam site to 98% at the Mid-reservoir Site. These mean values are below the state water quality criteria established for cold water fisheries of dissolved gases less than 110% of saturation.

Table 3.11 Summary of Current (1999–2006) Dissolved Oxygen Saturation Data Corrected for Depths >1 Meter in Nine Mile Reservoir

Site Name	N	Mean	Median	Maximum	Minimum	Standard Deviation
Dam Site	47	88%	89%	192%	2%	50%
Mid-reservoir Site	26	98%	106%	168%	10%	48%

Table 3.12 Percent of Total Samples in Exceedance of Dissolved Oxygen Saturation Criteria in Surface Samples (<110%)

Site Name	2000	2001	2002	2004	2005	2006	Mean
Dam Site	67%	33%	67%	50%	50%	67%	55%
Mid-reservoir Site	100%	100%	100%	75%	50%	100%	80%

There do remain exceedances of the dissolved oxygen saturation criteria in samples collected at the reservoir surface (less than 1 meter of depth).

Mean surface dissolved oxygen saturation data range from 128% to 138% with maximum values of 194% and 168%. Although such high dissolved oxygen saturation values during the day are often used to indicate the presence of photosynthesizing algae, the data for the Nine Mile Reservoir do not correlate well with chlorophyll-*a* measurements in the reservoir. High dissolved oxygen saturation values do, however, correspond to exceptionally warm water temperatures. One potential explanation for the high dissolved oxygen values observed at the surface of Nine Mile Reservoir is diurnal temperature swings. As water becomes colder at night, it is able to

Table 3.13 Summary of Current (1999–2006) Surface Dissolved Oxygen Saturation Data (<1 meter) in Nine Mile Reservoir

Site Name	N	Mean	Median	Maximum	Minimum	Standard Deviation
Dam Site (corrected data)	22	128%	115%	194%	81%	34%
Mid-reservoir Site (corrected data)	10	138%	146%	168%	104%	26%

absorb more oxygen. As the water is warmed during the day, the saturation level of the water is lowered. However, it may take several hours for oxygen to be released from the reservoir, resulting in elevated dissolved oxygen saturation levels observed during daytime hours. These diurnal trends can not be directly analyzed for Nine Mile Reservoir because no diurnal temperature or dissolved oxygen data have been collected. A water temperature swing of 7°C, which is a reasonable expectation of diurnal swings in Nine Mile Reservoir, relates to a 1 mg/L change in dissolved oxygen at saturation. Assuming this 7 degree flux spans 17 to 25°C (the observed high temperature in Nine Mile Reservoir), the 1 mg/L change in dissolved oxygen is related to a flux in DO of 25%.

Although dissolved oxygen saturation exceedances are observed at the surface of Nine Mile Reservoir, supersaturation does not extend throughout the water column, is unlikely to impose a severe stress to fish, and does not cause an impairment of the cold water fishery beneficial use.

3.5.2.3 Nitrate

The water quality criterion for nitrate established by the State of Utah is 4 mg/L. Values greater than 4 mg/L are considered to be in exceedance of state water quality criteria. Mean nitrate concentrations in Nine Mile Reservoir are quite low, with a mean concentration of 0.3 mg/L at both reservoir monitoring sites. Maximum concentrations range from 2.13 mg/L at the dam to 1.34 mg/L at the Mid-reservoir Site. These low concentrations are maintained throughout the season despite high nitrate concentrations in the inflow to Nine Mile Reservoir. Mean concentrations in the springs discharging to the reservoir and the reservoir inflow range from 2.26 mg/L to 2.63 mg/L. High concentrations of nitrate in the spring water discharging to Nine Mile Reservoir indicate high concentrations of nitrate in local groundwater. Groundwater also feeds the inflow to Nine Mile Reservoir especially at times when water is not being diverted from Six Mile Creek. However, the reservoir itself does not show signs of elevated nitrate.

Table 3.14 Summary of Current (1999–2006) Nitrate Data in Nine Mile Reservoir Watershed.

Site Name	N	Mean	Maximum	Minimum	Standard Deviation
Inflow	14	2.63	6.52	0.03	2.92
Dam Site	35	0.34	2.13	0.03	0.39
Mid-reservoir Site	20	0.32	1.18	0.03	0.32
Six Mile Creek above San Pitch confluence	15	0.95	2.80	0.29	0.68
Springs discharging to the reservoir	3	2.26	6.70	0.03	3.84

No exceedances of the nitrate criteria (no greater than 4.0 mg/L) were observed in either of the in-reservoir datasets. Six Mile Creek diversion inflow data show no nitrate criteria exceedances. Spring inflow data (although a relatively small dataset) show only one exceedance from the northern-most spring with the lowest inflow volume. However, inflow data to the reservoir show routine exceedances of the nitrate criteria of 4.0 mg/L.

Table 3.15 Percent of Total Samples in Exceedance of Nitrate Criteria (<4 mg/L) in Current Data (1999–2006).

Site Name	2000	2001	2002	2004	2005	2006	Mean
Inflow	100%	--	100%	100%	0%	0%	36%
Dam Site	0%	--	0%	0%	0%	0%	0%
Mid-reservoir Site	0%	--	0%	0%	0%	0%	0%
Six Mile Creek above San Pitch confluence	--	0%	0%	--	--	0%	0%
Outflow	--	--	--	--	--	0%	0%
Springs discharging to reservoir	--	--	--	--	--	33%	33%

3.5.2.4 pH

High pH values are observed routinely throughout Nine Mile Reservoir as well as the springs and inflow discharging to the reservoir. Mean reservoir pH is above 9.0 at both sites with maximum pH values over 10 at the Dam Site in the late summer months.

Table 3.16 Summary of Current (1999–2006) pH Data in Nine Mile Reservoir Watershed

Site Name	N	Mean	Maximum	Minimum	Standard Deviation
Inflow	18	8.25	8.73	7.79	0.29
Dam Site	149	9.01	10.07	7.47	0.56
Mid-reservoir Site	100	9.10	9.86	8.02	0.43
Six Mile Creek above San Pitch confluence	37	8.41	8.97	7.27	0.30
Six Mile Creek at diversion	1	7.15	7.15	7.15	
Springs discharging to reservoir	5	8.11	8.44	7.40	0.41
Reservoir outflow	2	8.08	8.7	7.46	0.88

Exceedances of the water quality criteria for pH (no greater than 9.0 and no less than 6.5) occur routinely in Nine Mile Reservoir. All observed exceedances were for high pH (alkaline) conditions. The mid-reservoir dataset for Nine Mile Reservoir shows 60% exceedance of the pH criteria. The dataset collected near the dam shows 54% exceedance, with maximum values greater than 10 observed. In the following figures (Figure 3.4), the solid lines represent the upper (9.0) and lower (6.5) limits of the pH range defined by the state water quality criteria.

Table 3.17 Percent of Total Samples in Exceedance of pH criteria (<9)

Site Name	2000	2001	2002	2004	2005	2006	Mean
Inflow	0%	--	0%	0%	0%	0%	0%
Outflow	--	--	--	--	--	0%	0%
Dam Site	82%	--	0%	63%	52%	63%	54%
Mid-reservoir Site	92%	--	0%	83%	49%	76%	60%
Six Mile Creek above San Pitch confluence	--	0%	0%	--	--	0%	0%
Six Mile Creek at diversion	--	--	--	--	--	0%	0%
Springs discharging to the reservoir	--	--	--	--	--	0%	0%

While pH values observed in Six Mile Creek water quality monitoring were elevated (averaging 8.5), exceedances of the upper pH criteria of 9.0 did not occur in any of Six Mile Creek diversion inflow data. Observed exceedances of the pH criteria occur more frequently in the later summer months. The incidence and magnitude of exceedance increase with time as the summer progressed, with the highest pH values recorded in the month of September (Figure 3.4). This trend correlates well with the diversion of less alkaline water from Six Mile Creek from June 15 to August 15. During this period, the less alkaline diversion water dilutes the high pH water in Nine Mile Reservoir and the incoming spring water. Once the diversion ends, the dilution process ceases and pH values go back to their natural level of just over 9.

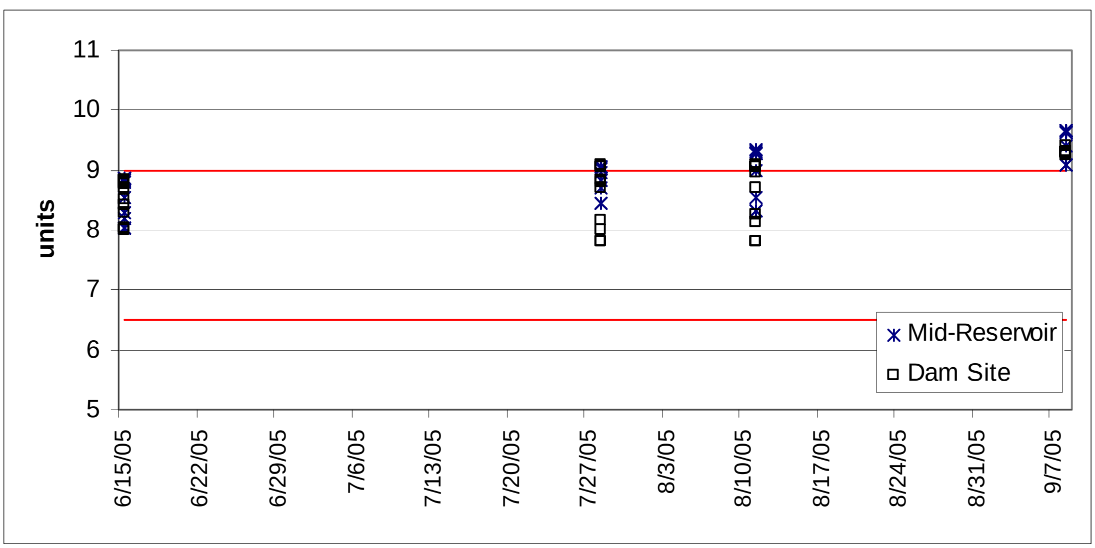


Figure 3.4 pH values in Nine Mile Reservoir showing seasonal trend as observed during 2005 routine monitoring.

Due to the occurrence of high pH soils near and underlying portions of the reservoir, an attempt was made to characterize the contribution of soil pH to the level of pH criteria exceedance observed in the reservoir. Local and watershed soils are alkaline in nature, especially those soils located near and under the southwest edge of the reservoir, which are highly alkaline in nature. A soil analysis completed for the area surrounding Nine Mile Reservoir assessed that the alkaline soils near the reservoir have a particularly high pH range of 8 to 10. (Figure 3.5) It is also assumed that the alkaline soils extend underneath the Nine Mile Reservoir and naturally contribute to the alkalinity to the reservoir water. Soil leaching processes may therefore act as a source of elevated pH levels in the reservoir. Thus, impairments associated with pH in Nine Mile Reservoir are associated with naturally occurring conditions and can therefore not be corrected with management practices.

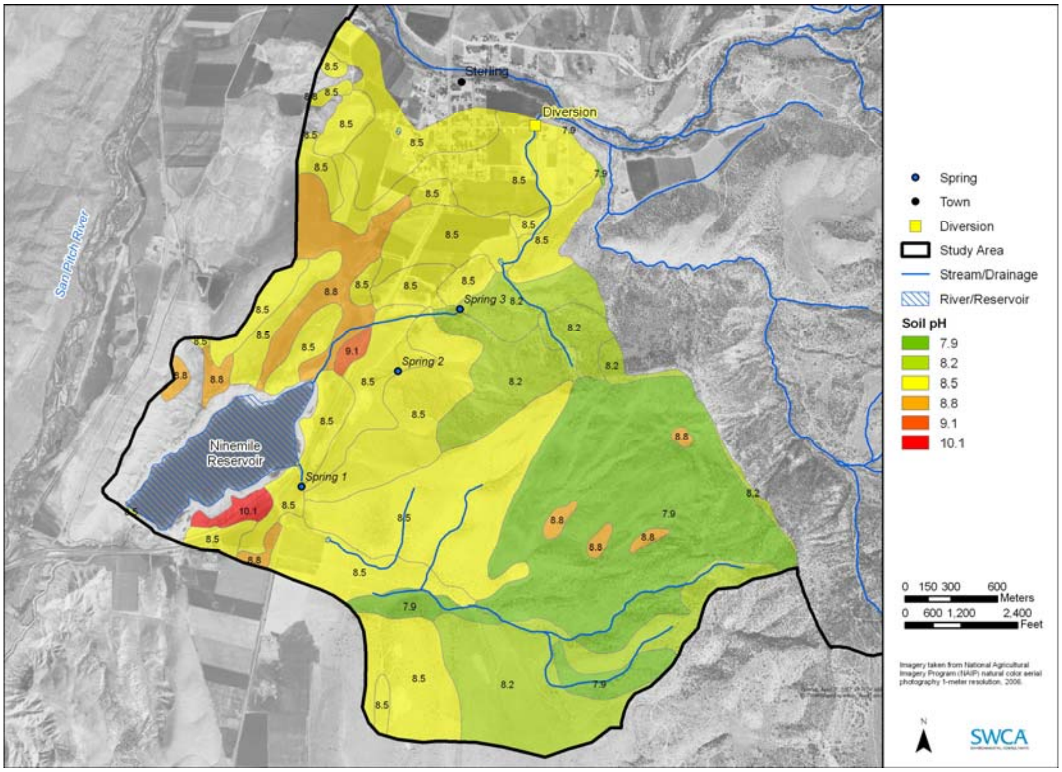


Figure 3.5 pH of soils in Nine Mile Reservoir watershed.

3.5.2.5 Temperature

High temperature values are routinely observed in Nine Mile Reservoir. Mean temperature at both reservoir sites is 20°C with maximum values greater than 24°C observed in the summer months.

Exceedances of the water quality temperature criteria for cold water game fish (no greater than 20°C) occur routinely in both reservoir datasets. The Mid-reservoir Site dataset showed 53% exceedance of the 1-day average criteria. The dataset collected at the Dam Site also showed 49% exceedance. Exceedances of the coldwater temperature criteria occurred in approximately 10% of the Six Mile Creek data (sampled above the confluence with the San Pitch River), and in 60% of the spring inflow data.

Since the reservoir has little natural cover and the watershed is located in an area experiencing warm, dry climate conditions, the State of Utah recently conducted an assessment of temperature inputs to several local water bodies and determined that the primary source of temperature loading was from solar radiation and heat transfer. Temperature increases in Nine Mile Reservoir are influenced by natural heat exchange through high air temperatures and the effects of direct solar radiation on the water surface, especially during the summer. In addition, inflowing tributaries in hot climates can contribute to temperature increases particularly in the summer (See Figure 2.3 for average daily air temperatures in the general area of the watershed.). Exceedances of the cold water temperature criteria occurring in the Six Mile Creek diversion inflow and spring inflow indicate that both inflow and in-reservoir heating processes are responsible to some degree for the elevated water temperatures observed. Furthermore, native vegetation in all but the highest elevations of most drainages is relatively low-growing and sparse and provides little shade on major tributaries. These environmental factors play a major role in raising water temperatures in Nine Mile Reservoir. Despite exceedances of the state criteria, Nine Mile Reservoir was not determined to be impaired for temperature due to natural heat loading. The assessment of temperature exceedance in this document is specific to the determination of designated use support status for cold water game fish only.

Table 3.18. Summary of Current Temperature Data (1999–2006) in Nine Mile Reservoir watershed

Site Name	N	Mean	Maximum	Minimum	Standard Deviation
Inflow	18	18.33	26.41	12.43	3.37
Dam Site	136	20.04	25.80	14.08	2.85
Mid-reservoir Site	100	20.22	24.36	13.80	2.61
Six Mile Creek above San Pitch confluence	21	10.21	21.81	0.35	6.86
Six Mile Creek at diversion	1	20.30	20.30	20.30	--
Springs discharging to the reservoir	5	18.06	22.30	12.00	5.36
Reservoir outflow	2	20.9	21.4	20.4	0.71

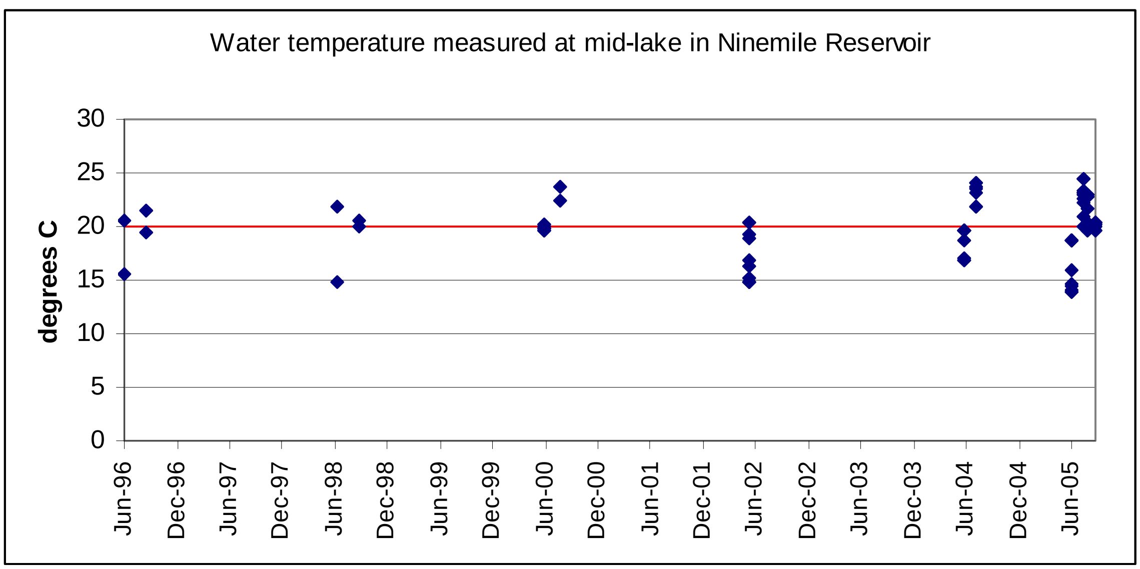


Figure 3.6 Water temperatures observed during routine monitoring at the Mid-reservoir Site in Nine Mile Reservoir.

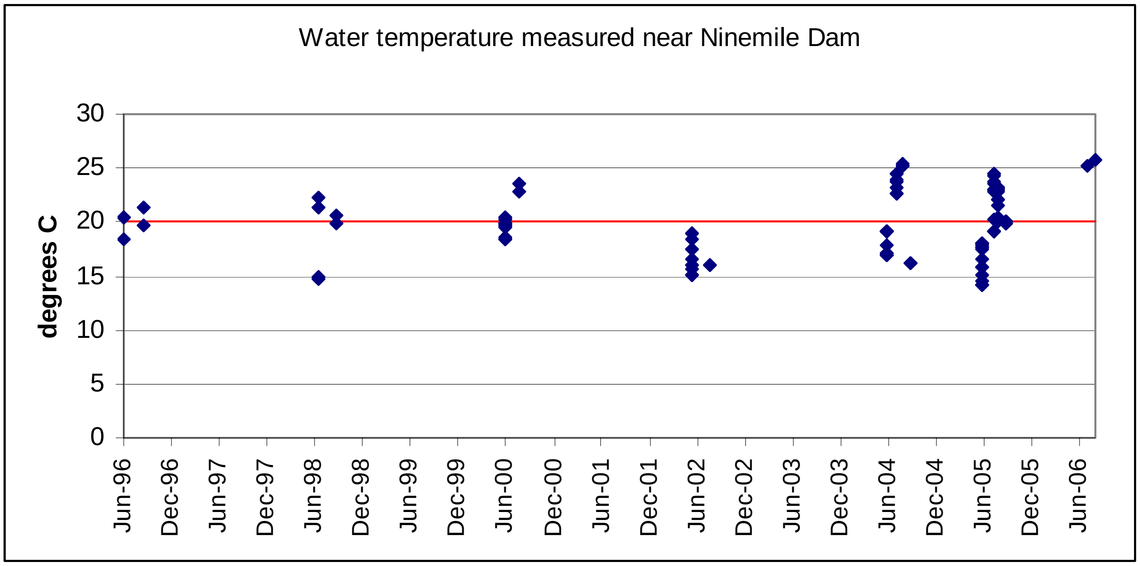


Figure 3.7 Water temperatures observed during routine monitoring near the Dam Site in Nine Mile Reservoir.

3.5.2.6 Total Dissolved Solids

Data collected between 1999 and 2006 indicate that total dissolved solids (TDS) concentrations are moderate in Nine Mile Reservoir, with a mean concentration at the Dam Site of 480 mg/L. The maximum observed TDS concentration in Nine Mile Reservoir is 854 mg/L, well below the water quality criteria of 1,200 mg/L established by the State of Utah. (Table 3.19) High concentrations of TDS are observed in the springs discharging to the reservoir, indicating high dissolved solids in the groundwater. This is characteristic of waters in other parts of the San Pitch River basin (UDWQ 2003).

Table 3.19 Summary of Current Total Dissolved Solids Data (1999 – 2006) in Nine Mile Reservoir Watershed.

Site Name	N	Mean	Maximum	Minimum	Standard Deviation
Inflow	15	510	796	224	182
Outflow	2	358	490	225	187
Dam Site	15	480	854	336	136
Six Mile Creek above San Pitch confluence	15	410	890	214	208
Six Mile Creek at diversion	1	225	225	225	--
Springs discharging to the reservoir	6	711	1300	321	378

The available data show no total dissolved solids concentrations in the reservoir that exceed either the 1,200 or the 2,000 mg/L criteria (Table 3.19). All concentrations are well below 1,000 mg/L. TDS in the springs discharging to the reservoir exceed the TDS criteria of 1,200 mg/L 17% of the time (Table 3.20).

Table 3.20 Percent of Total Samples in Exceedance of Total Dissolved Solids Criteria (<1200 mg/L)

Site Name	2000	2001	2002	2004	2005	2006	Mean
Inflow	0%		0%	0%	0%	0%	0%
Dam Site	0%		0%	0%	0%	0%	0%
SIX MILE CK AB CNFL / SAN PITCH R NW OF STERLING	--	0%	0%	--	--	0%	0%
Outflow	--	--	--	--	--	0%	0%
Springs discharging to the reservoir	--	--	--	--	--	17%	17%

3.5.2.7 Total Phosphorus

Total phosphorus concentrations are generally quite low in Nine Mile Reservoir (Table 3.21). More than half of the phosphorus data collected in Nine Mile Reservoir were recorded as nondetect, and therefore assumed to be half of the detection limit for the purposes of analysis. The prevalence of nondetect values in the reservoir brings the estimated median concentration down to 0.005 mg/L (which is equal to half of the detection limit for most of the phosphorus data collected in the reservoir). Mean concentrations are also very low and range from 0.01 mg/L at the Dam Site to 0.023 mg/L at the Mid-reservoir Site. The maximum concentrations of 0.257 mg/L at the Mid-reservoir Site and 0.068 mg/L at the Dam Site are correlated with low water levels in the reservoir. (See Section 3.4.2.2.2) As the reservoir is drawn down for irrigation, phosphorus associated with the sediment-water interface becomes available for algal growth due to shallow water conditions and more access to light. Phosphorus associated with the sediment-water interface with the reservoir full is generally unavailable for algal growth because light does not typically reach to such depths.

Table 3.21 Summary of Current Total Phosphorus Data (1999 – 2006) in Nine Mile Reservoir Watershed.

Site Name	N	Mean	Maximum	Minimum	Standard Deviation
Inflow	15	0.033	0.261	0.005	0.067
Dam Site	35	0.009	0.068	0.005	0.012
Mid-reservoir Site	20	0.023	0.257	0.005	0.057
Six Mile Creek above San Pitch confluence	15	0.017	0.070	0.005	0.021
Springs discharging to the reservoir	3	0.011	0.016	0.006	0.005
Reservoir outflow	1	0.083	0.083	0.083	--

The State of Utah has not identified a criterion for phosphorus concentration. State water quality guidance has established an indicator value of 0.025 mg/L total phosphorus concentration in lakes and reservoirs as a trigger for further, in-depth assessment of water body condition and needs. A threshold of 0.05 mg/L has been established for streams in Utah.

Total phosphorus concentrations observed in both reservoir datasets contain isolated threshold value. Approximately 6% of the data collected at the Mid-reservoir Site exceeds the 0.025 mg/L indicator value and approximately 10% of the data collected near the dam shows values greater than the indicator. Total phosphorus concentrations measured in Six Mile Creek exceed the stream phosphorus indicator value of 0.05 mg/L 13% of the time. Diversion inflow data and spring inflow data do not exceed the indicator concentration of 0.025 mg/L. However, 20% of the data collected at the inflow to the reservoir exceed this threshold concentration.

Table 3.22 Percent of Total Samples in Exceedance of Total Phosphorus Indicator Threshold (<0.05 mg/L for streams and <0.025 mg/L for reservoirs)

Site Name	2000	2001	2002	2004	2005	2006	Mean
Inflow	50%	--	0%	0%	20%	20%	20%
Dam Site	33%	--	20%	0%	0%	0%	6%
Mid-reservoir Site	25%	--	0%	0%	17%	0%	10%
Six Mile Creek above San Pitch confluence	--	0%	25%	--	--	17%	13%
Springs discharging to the reservoir	--	--	--	--	--	0%	0%

3.5.3 TREND ANALYSIS

3.5.3.1 Chlorophyll *a*

Chlorophyll *a* is a pigment found in plants for use in photosynthesis. The amount of chlorophyll *a* contained in the reservoir is an indicator of phytoplankton production and is used as an indicator of eutrophication in waters. While the State of Utah does not publish criteria for acceptable levels of chlorophyll *a*, one review regarding nuisance thresholds and chlorophyll *a* standards reported that chlorophyll *a* concentrations of 10–15 µg/L protect waters inhabited by salmonids (Pilgrim et al. 2001). Several states in the U.S. and provinces in Canada have stated that a range of 15 to 50 µg/L maximum chlorophyll *a* concentrations is ideal for protecting aesthetic value and recreational uses. Data on water discoloration (Rashke 1994) show that a level of discoloration deemed acceptable to the average recreational user commonly occurs at chlorophyll *a* concentrations between 10–15 µg/L. Above this concentration, deep discoloration is observed to occur, along with the formation of algal scum, reducing aesthetics and recreational use.

Current median in-reservoir chlorophyll *a* concentrations range from 0.7 µg/L at the Mid-reservoir Site to 1 µg/L at the Dam Site. Mean concentrations are slightly higher ranging from 2.5 µg/L at the Mid-reservoir Site to 3.8 µg/L at the Dam Site, based on data collected from 1996 to 2006 (Figure 3.8).

Table 3.23 Summary of Current (1999–2006) Chlorophyll *a* Data (µg/L) in Nine Mile Reservoir.

Site Name	N	Mean	Median	Maximum	Minimum	Standard Deviation
Dam Site	12	3.8	1	17.6	0.4	5.4
Mid-reservoir Site	8	2.5	0.7	15.5	0.4	5.3

With the exception of a sampling period in 2006, all of the chlorophyll *a* data collected during recent monitoring of Nine Mile Reservoir were below 10 µg/L at both the Dam Site and the Mid-reservoir Site. Until 2006, mean chlorophyll *a* levels had been decreasing.

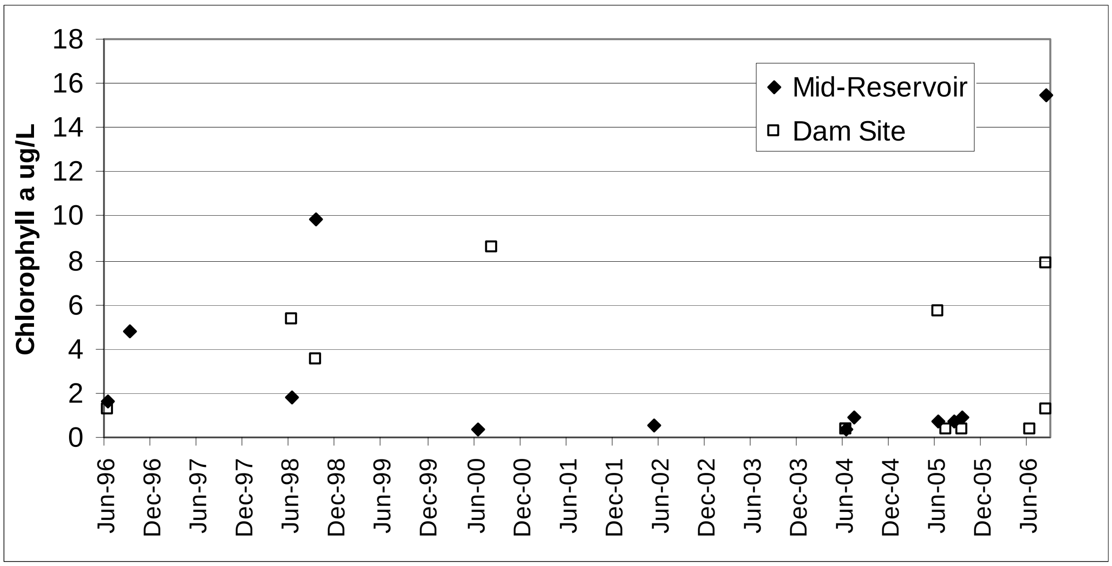


Figure 3.8 Chlorophyll-*a* trend data for Nine Mile Reservoir.

3.5.3.2 Secchi Depth

Secchi depth is a measurement of the clarity or transparency of surface waters. Secchi depths are measured using a disk with alternating black and white sections that is lowered into the water. When the disk is no longer visible, the "Secchi depth" is recorded. For example, a Secchi depth of three feet indicates that the disk was last visible at three feet below the surface. High Secchi depth readings indicate that the water is relatively clear and will allow sunlight to penetrate to greater depths. Low readings indicate turbid water (due to algae growth, suspended sediment, or other causes), which can reduce the depth to which sunlight can penetrate. Limited light at lower depths can result in decreased growth of aquatic plants. Secchi depth measurements, in meters, were reported for the 1996 through 2006 period. According to the reported values taken at both the Dam Site and Mid-reservoir Site, the Secchi depth readings have generally stayed constant with a slight improvement in transparency observed since 1998.

In most cases, the Secchi depths recorded for Nine Mile Reservoir (Figure 3.9) show an increasing trend over time during the summer growing season. Data collected in 2006 are slightly lower than in past years and are likely related to higher chlorophyll *a* values during this same sampling period. Low Secchi depth values also reflect non-algal turbidity associated with dissolved organic carbon or carbonate alkalinity (Carlson 1992).

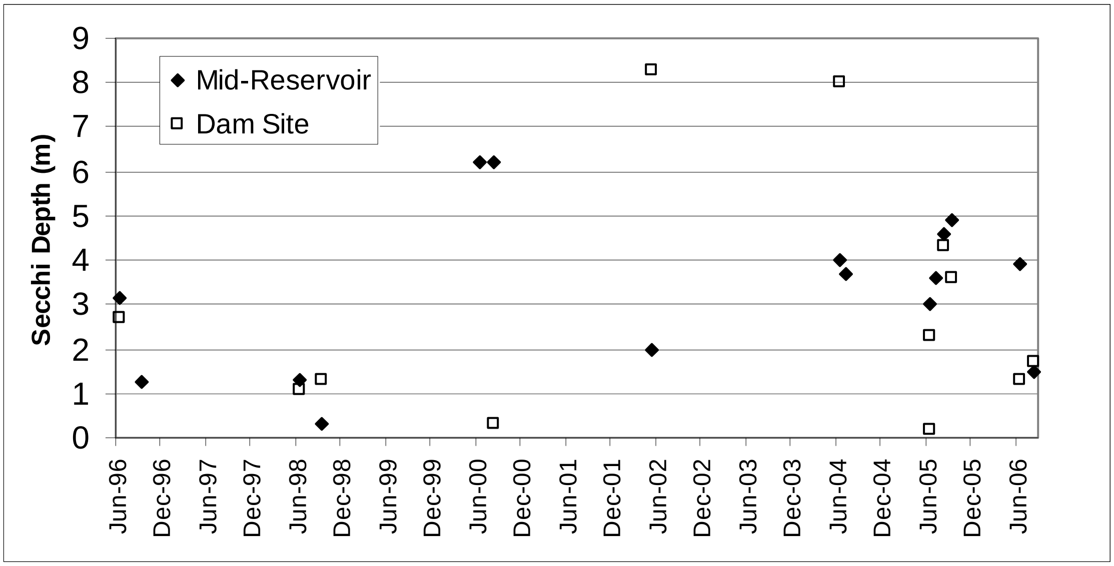


Figure 3.9 Secchi depth trend data for Nine Mile Reservoir.

3.5.3.3 Total Phosphorus

The numeric criterion for total phosphorus is 0.025 mg/L in lakes and reservoirs. This is not considered a water quality standard but a pollution level indicator that is used along with other water quality parameters to assist in the determination of the reservoir impairment. The levels of total phosphorus have been at levels which are primarily lower than the indicator threshold for total phosphorus, especially in the later portion of the reporting period (Figure 3.10). Total phosphorus concentrations show a generally decreasing trend in the reservoir.

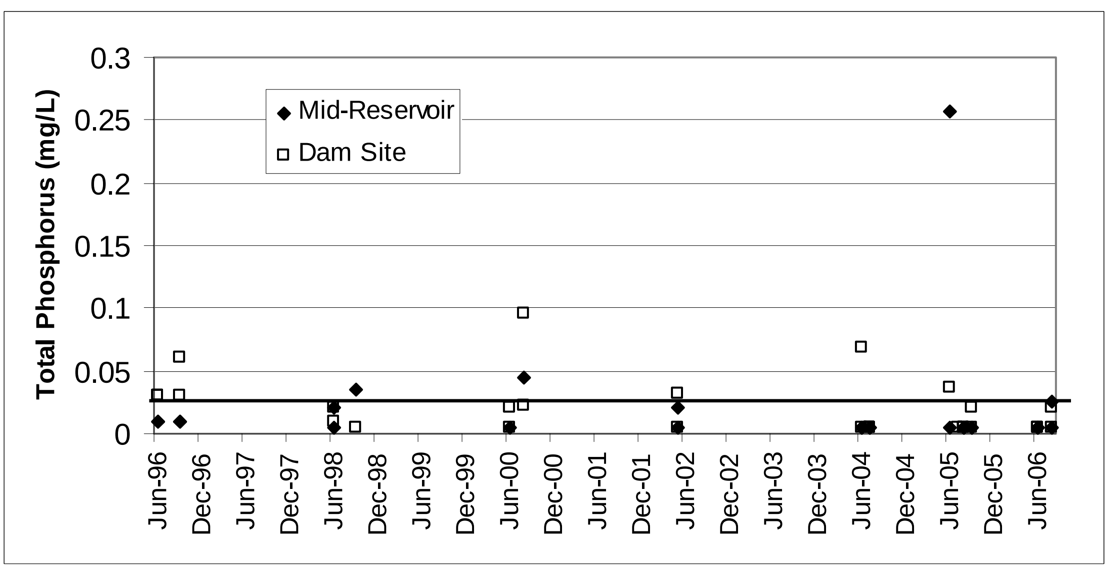


Figure 3.10 Total phosphorus trend data for Nine Mile Reservoir.

3.5.4 Reservoir Water Column Data Assessment

3.5.4.1 Data and Analytical Methods

This section describes a more in-depth analysis of reservoir stratification and dynamics as well as water column habitat and fishery health. Water column data for temperature, pH, and dissolved oxygen were evaluated using the percentage-based criteria established by the State of Utah specifically for dissolved oxygen. The dataset used in this assessment was the in-reservoir depth integrated monitoring information provided by UDWQ. Depth integrated data are available for both the Mid-reservoir Site and the Dam Site and are presented in Table 3.24.

Table 3.24 Depth-integrated Reservoir Monitoring Data

	Mid-reservoir Site						Dam Site				
	2000	2002	2004	2005	2006		2000	2002	2004	2005	2006
May		✓						✓			
June	✓		✓	✓	✓		✓		✓	✓	✓
July			✓	✓					✓	✓	
August				✓	✓				✓	✓	✓
September				✓						✓	

3.5.4.2 Reservoir Stratification

Representative depth profile plots of dissolved oxygen, temperature, and pH are displayed for spring, summer, and fall conditions (2005) observed in Nine Mile Reservoir at the Mid-reservoir and Dam Sites (Figures 3.11 to 3.14). Depth increases down the vertical axis of each of the plots displayed. To read the plots, assume that the lower horizontal axis represents the bottom (or floor) of the reservoir and the top of the plot represents the water surface.

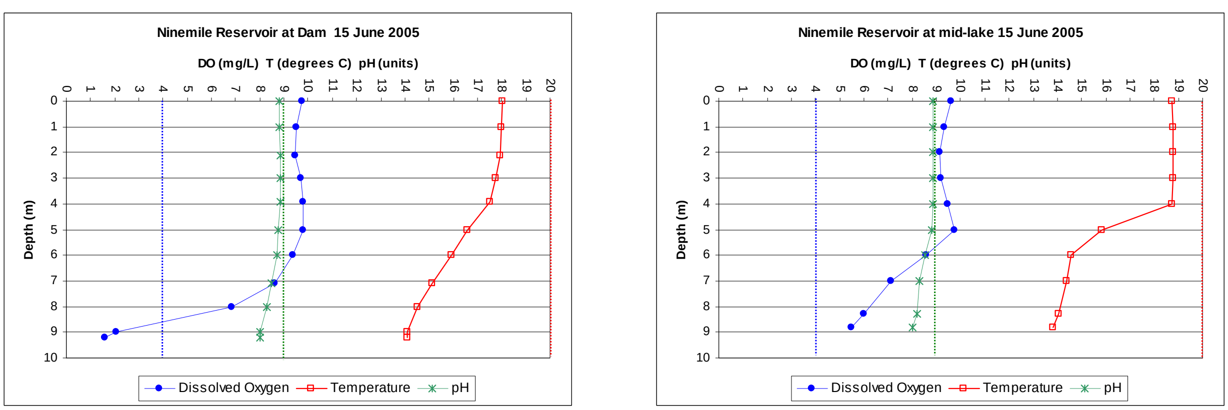


Figure 3.11 Spring (15 June 2005) depth profile plots for dissolved oxygen, temperature, and pH observed in Nine Mile Reservoir.

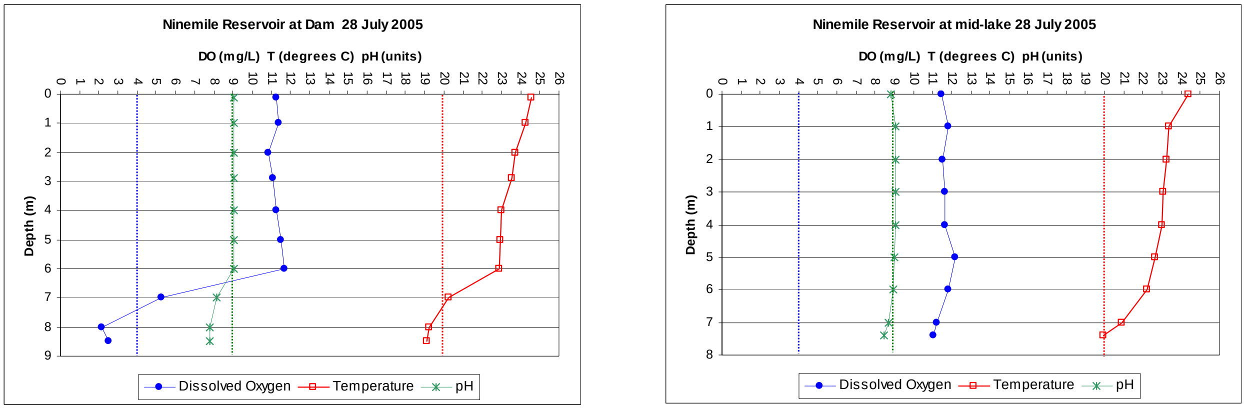


Figure 3.12 Summer (28 July 2005) depth profile plots for dissolved oxygen, temperature, and pH observed in Nine Mile Reservoir.

Dissolved oxygen, temperature, and pH data are plotted on separate curves on each of the figures. Data are displayed for both in-reservoir sites. Depths at the Mid-reservoir Site are generally shallower than those taken at the Dam Site. Depth integrated data from 2005 were selected for display here as they represent the year with the best overall seasonal coverage and relatively average flow conditions (Figures 3.11 to 3.14).

The 2005 water year followed an extended period of drought in the watershed and the Sevier River basin, and may be representative of in-channel purge/flush conditions where sedimentation and deposition processes occur to a greater extent upstream in low flow (drought) conditions, and higher flow events associated with average water conditions result in a surge of deposited material being delivered to downstream water bodies. These data cannot therefore be considered completely representative of average water year conditions in the Nine Mile Reservoir watershed but provide a good illustration of seasonal changes in dissolved oxygen, temperature, and pH within the reservoir.

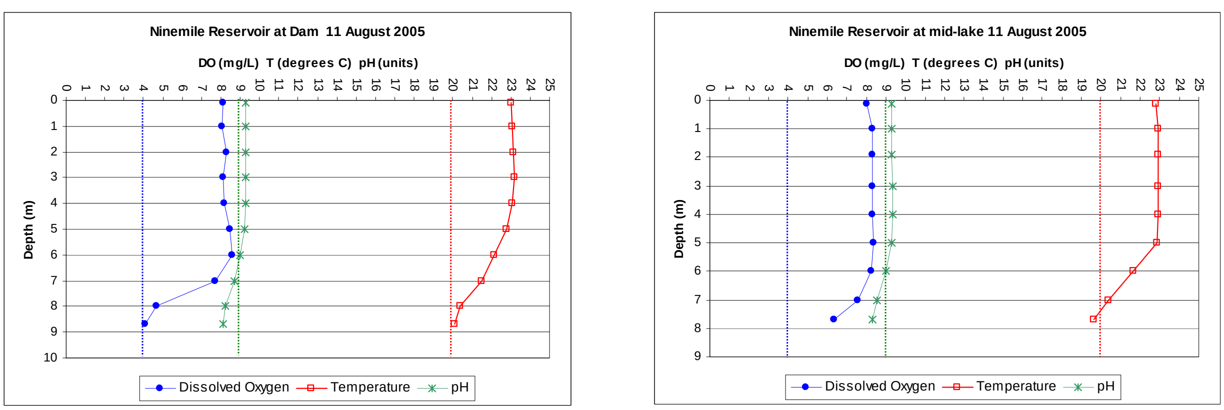


Figure 3.13 Summer (11 August 2005) depth profile plots for dissolved oxygen, temperature and pH observed in Nine Mile Reservoir.

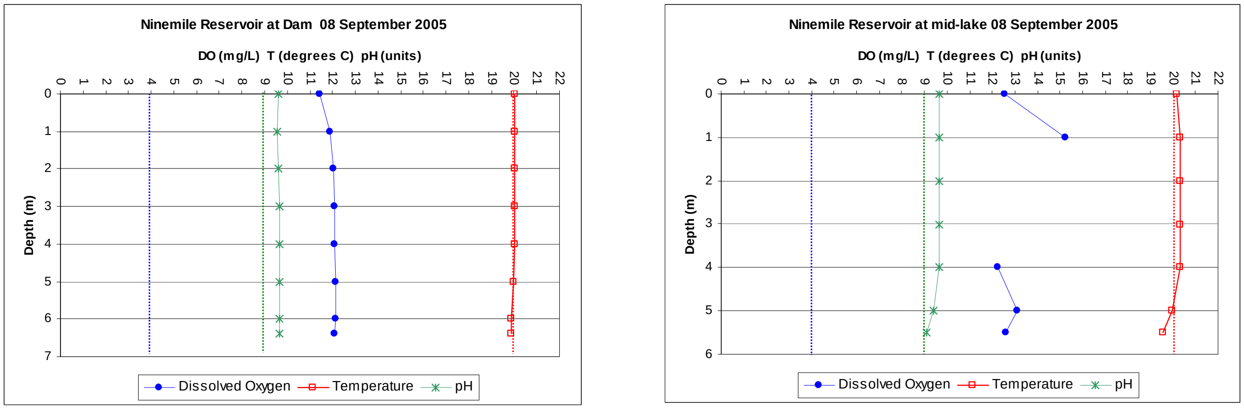


Figure 3.14 Fall (08 September 2005) depth profile plots for dissolved oxygen, temperature and pH observed in Nine Mile Reservoir.

Drought or low water year conditions can be assumed to result in warmer water temperatures and lower dissolved oxygen levels, while high water year conditions can be expected to result in deeper water levels and lower water temperatures. As a managed system, these year-to-year variations are likely not as noticeable as in free-flowing, non-impounded systems like natural lakes.

Figure 3.11, displaying June 2005, depth-integrated data shows some stratification occurring within the reservoir (a condition where dissolved oxygen and temperature change specific to depth; lower water layers are generally cooler while upper water layers experience higher temperatures). Stratification is noticeably stronger at the Dam Site with a marked thermocline occurring between 4 and 5 meters deep. A thermocline is a location in the water body where temperature changes by more than $1^{\circ}C$ within a 1 meter change in depth. When strongly established, thermoclines can act to resist mixing, and can lead to low dissolved oxygen in the lower layers of a reservoir as decomposition removes oxygen from the water column and thermal inertia discourages mixing of the better aerated surface layers.

Dissolved oxygen concentrations and water temperatures at the Mid-reservoir Site are not in exceedance of water quality criteria, while dissolved oxygen in the lower depths near the dam (below 9 meters) show concentrations below 4.0 mg/L, though these occur in less than 25% of the water column. Because fish and most other aquatic life species are mobile and can relocate to areas of suitable habitat in the event of a localized criteria exceedance, the State of Utah has defined the support status of game fish populations relative to the percentage of the total water column experiencing depressed dissolved oxygen concentrations. In terms of dissolved oxygen, a water body is defined to be non-supporting for cold water game fish when more than 75% of the water column exceed dissolved oxygen criteria, partially supporting if 50 to 75% of the water column depth exceed criteria, and fully supporting where less than 50% of the water column exceed criteria. These criteria were assessed for dissolved oxygen in Section 3.5.2.1.

Conditions in July 2005 (Figure 3.12) present a marked contrast to the June profiles. Stratification is noticeably stronger at the Dam Site, with a marked thermocline between 6 and 7 meters deep, while the Mid-reservoir Site is noticeably mixed. Dissolved oxygen concentrations at the Mid-reservoir Site are indicative of in-reservoir growth processes, and water temperatures are noticeably higher than the cold water criteria through much of the water column. Dissolved oxygen concentrations in the lower depths near the dam (below about 7 meters) show conditions that are not supportive of cold water game fish. These low dissolved oxygen conditions are directly correlated with high water temperatures (above 20°C) in the overlying water column and act to reduce viable habitat. Fish trying to move deeper to escape warm water temperatures will encounter low dissolved oxygen concentrations in the lower levels of the reservoir. While the water column at the Mid-reservoir Site contains sufficient dissolved oxygen, there is no available depth at which temperatures are appropriate for cold water species.

Conditions in the August 2005 (Figure 3.13) water column for the reservoir present a similar situation to that observed for July, low dissolved oxygen concentrations in the reservoir depths are correlated with high water temperatures in the overlying layers and cumulatively act to reduce viable habitat for cold water species.

September 2005 conditions (Figure 3.14) show that substantial mixing and cooling has occurred within the water column at both in-reservoir sites. Dissolved oxygen concentrations, water temperatures, and pH values are nearly static from surface to depth and show that the shorter daylight hours and cooler air temperatures are affecting both reservoir waters and inflows. While pH exceedances are still occurring, dissolved oxygen and temperature are within criteria. Dissolved oxygen concentrations are still indicative of in-reservoir growth, but are not as critical as water temperatures are lower, allowing greater dissolution to occur.

3.5.4.3 Habitat Viability

Since multiple stressors can have an added detrimental impact on aquatic life (for example both temperature and dissolved oxygen being in exceedance of the defined criteria simultaneously), an additional assessment was completed examining the occurrence of two or more water quality exceedances in the water column at the same time and place. Assuming that viable habitat is defined as no observed exceedances of dissolved oxygen, temperature, or pH criteria, and applying the depth distribution of percent water column (established for dissolved oxygen) out of compliance with water quality criteria, the Mid-reservoir Site was shown to have an average of more than 50% of the water column of viable habitat during the months of May and June for all years (except 2006) for which profiles were available. Depth-integrated data collected at the Mid-reservoir Site show that none of the water column, from surface to depth, could be defined as viable habitat for the months of June 2006, July 2004, and August 2005 and 2006. Data collected at this site show 100% of the water column experienced at least 1 parameter in exceedance of water quality criteria during the above months. Data collected during July 2005 show that 95% of the water column at this site experienced at least 1 parameter out of compliance. Annual average conditions compiled using available profile data show that 100% of the water column experienced at least one parameter out of compliance during the month of August (Table 3.25).

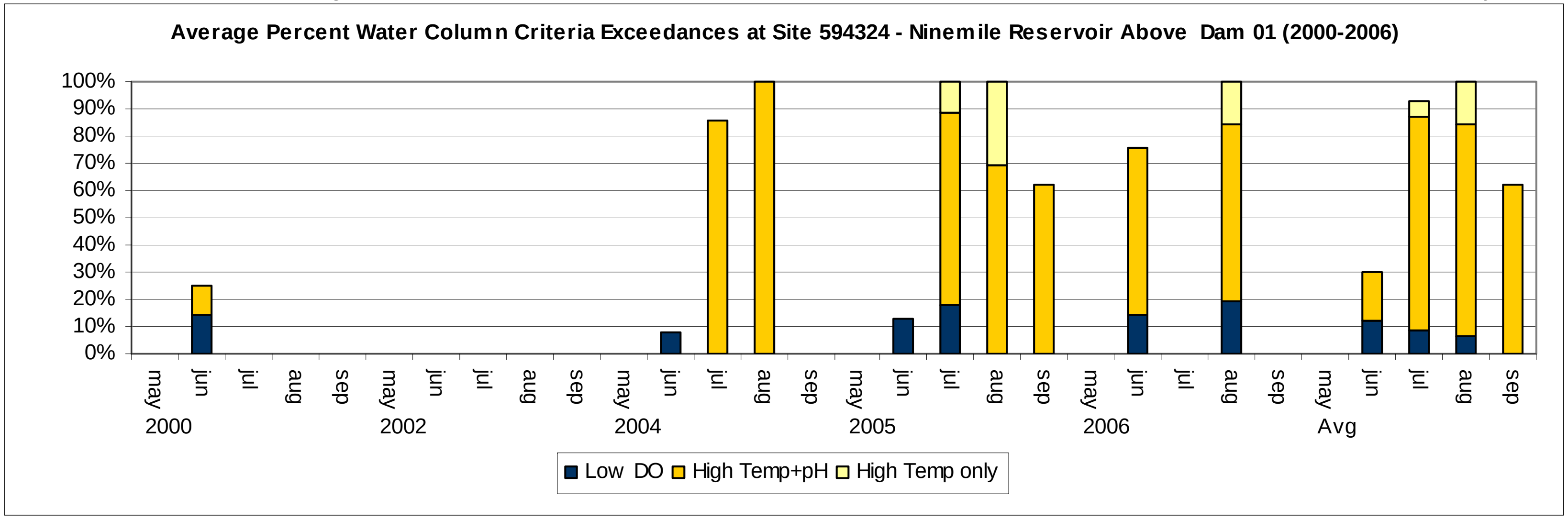
Table 3.25 Nine Mile Viable Habitat

Site Name	Month	2000	2001	2002	2004	2005	2006	Average
Dam Site	May	--	--	100%	--	--	--	100%
	June	75%	--	--	92%	87%	24%	70%
	July	--	--	--	14%	0%	--	7%
	Aug	--	--	--	0%	0%	0%	0%
	Sept	--	--	--	--	38%	--	38%
Mid-reservoir Site	May	--	--	84%	--	--	--	84%
	June	98%	--	--	94%	100%	0%	73%
	July	--	--	--	0%	5%	--	3%
	Aug	--	--	--	--	0%	0%	0%
	Sep	--	--	--	--	27%	--	27%

Depth-integrated data collected at the Dam Site show that none of the water column, from surface to depth, was in full compliance with water quality criteria for the months of July 2005, and August 2004, 2005 and 2006. Data collected at this site show 100% of the water column experienced at least 1 parameter in exceedance of water quality criteria during the above months. Data collected during June 2006 show that 76% of the water column at this site experienced at least 1 parameter out of compliance, also indicative of non-support. Data collected during September 2005 show that 62% of the water column at this site experienced at least 1 parameter out of compliance, indicating a partial support status. Annual average conditions compiled using available profile data show that 100% of the water column experiences at least one parameter out of compliance during the month of August (Table 3.25).

Figure 3.15 presents plots of the relative percent of the water column experiencing a single exceedance, multiple criteria excursions, and the relative amount of viable habitat available to fish for summertime monitoring years of 2000, 2002, 2004, 2005 and 2006. Figure 3.16 shows the relative percent of the water column that is viable habitat for coldwater fish species during the same time period.

During the months of July and August of all years for which there are profile data, nearly 100% of the water column at both sites is in exceedance of at least one criterion. The lack of viable habitat during these months is almost entirely attributed to naturally high pH values and elevated temperatures associated with the climate and hydrology of the reservoir. Low dissolved oxygen generally occurs in less than 15% of the water column. (Fig. 3.15)



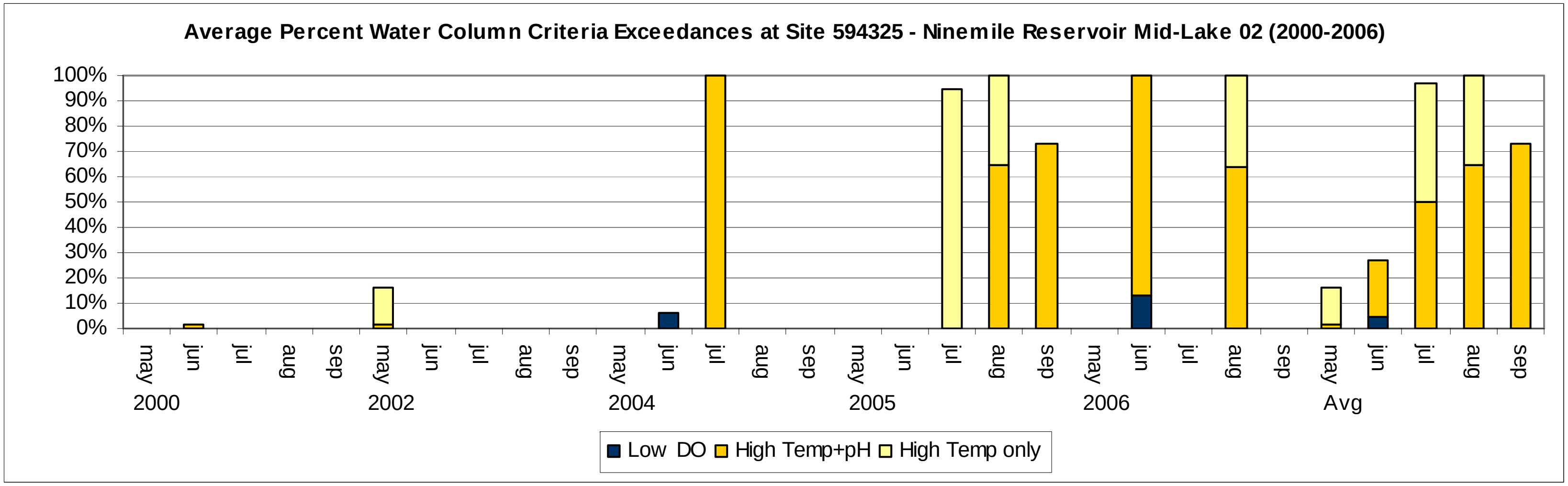
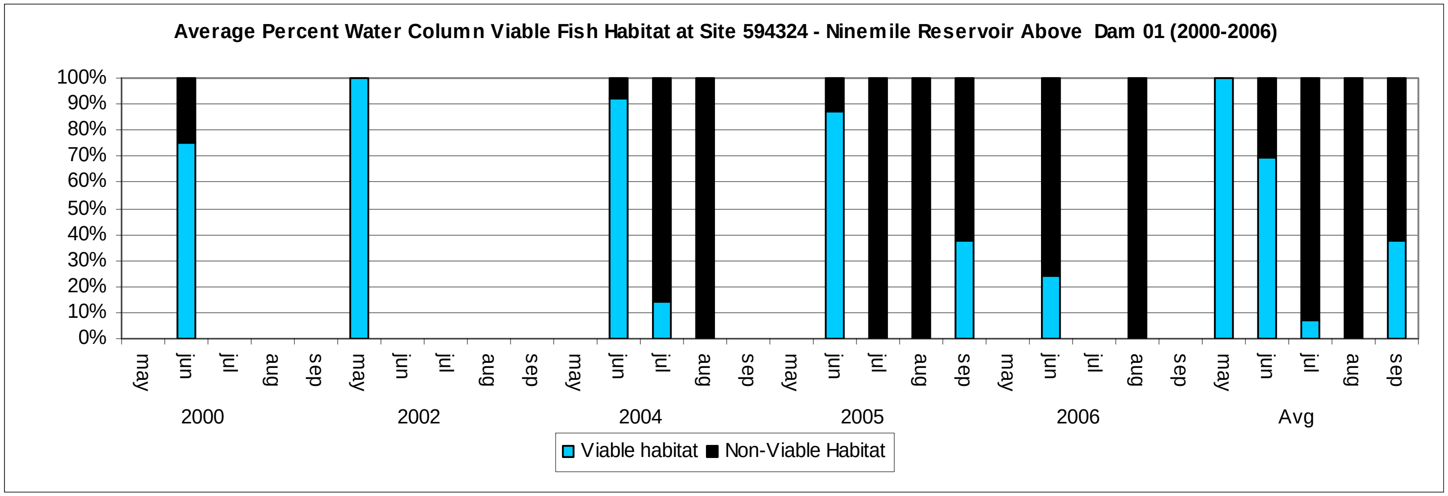


Figure 3.15 Relative percent of the water column at Mid-reservoir Site (upper plot) and near the Dam Site (lower plot) experiencing one or more exceedances of water quality criteria.



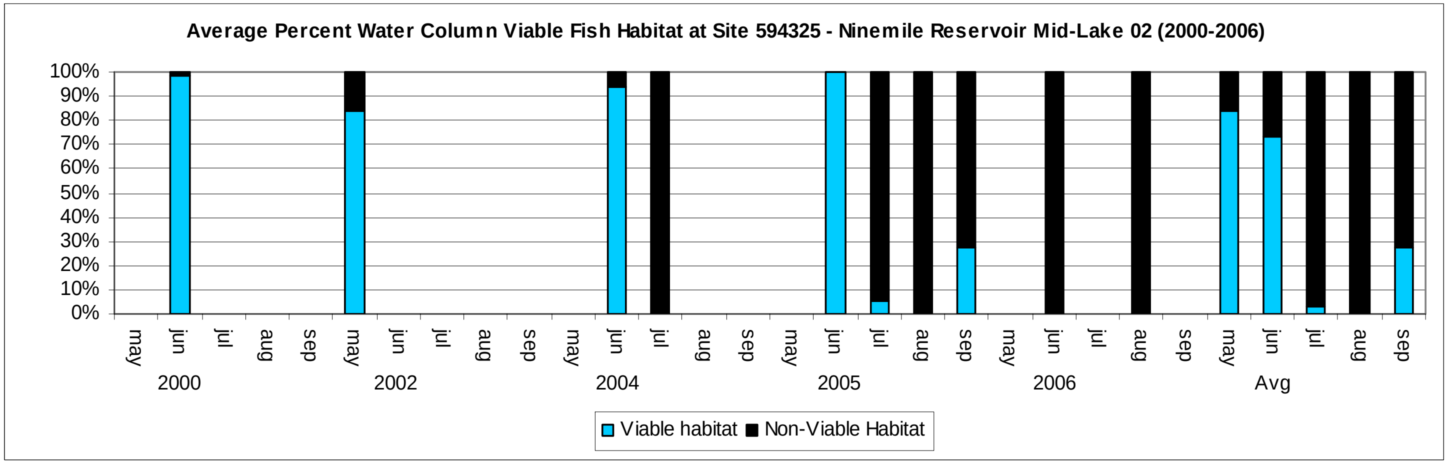


Figure 3.16 Relative percent of the water column at Mid-reservoir Site (upper plot) and near the Dam Site (lower plot) exhibiting viable habitat conditions. For the above plots, viable habitat condition was defined as that portion of the water column where no exceedances of water quality criteria (joint or single) were observed.

3.5.5 COMPARISON WITH PALISADES LAKE

3.5.5.1 Characteristics of Palisades Lake

Palisades Lake, a reservoir located about 2.3 miles northeast of Nine Mile Reservoir, receives water from Six Mile Creek and occupies soils similar to the majority of the watershed. Palisades Lake does not overlay the extremely alkaline soils associated with the southwest portion of Nine Mile Reservoir and does not receive appreciable spring water. All of the water in Palisades Lake is diverted from Six Mile Creek.

Palisades Lake is smaller than Nine Mile Reservoir, holding 1,728 acre-feet of water (approximately 1/2 the volume of Nine Mile Reservoir), and has a surface area of 28 acres (approximately 1/3 of the surface area of Nine Mile Reservoir). Palisades Lake is shallower than Nine Mile Reservoir with a maximum depth at Palisades Lake of 9.5 meters (31 feet) and a maximum depth at Nine Mile of 11 meters (36 feet). Dissolved oxygen data at the dam for Palisades Lake extend to 7.7 meters while dissolved oxygen data is available to a depth of 9.3 meters in Nine Mile Reservoir at the dam. Palisades Lake is not listed as impaired for low dissolved oxygen, although it is listed as impaired for high temperature on the State of Utah's 303(d) 2006 list of impaired waters. Therefore, comparison between the two water bodies provides additional evidence for recommending that Nine Mile Reservoir be removed form the 303(d) list of impaired waters.

The operation of the two reservoirs differs substantially, as Palisades Lake experiences much greater flow-through conditions than Nine Mile Reservoir. Therefore, a comparison of instantaneous water quality characteristics between the two reservoirs can help to identify water quality effects that are the result of watershed-based conditions and Six Mile Creek inflows. It cannot, however, be used to distinguish between water quality effects that result from flow-management and spring water inflows.

3.5.5.2 Water Quality Comparison

A direct comparison of the data available to the study is included in Table 3.26. Average water quality conditions in Palisades Lake closely mimic average conditions occurring in Six Mile Creek and Nine Mile Reservoir in all cases except alkalinity, minimum dissolved oxygen, pH at the dam, and salinity.

Average alkalinity observed in Palisades Lake is approximately 28% less than that in Nine Mile Reservoir. This is likely a direct result of the high-alkaline soils present in a portion of Nine Mile Reservoir.

Average dissolved oxygen levels observed at the dams are similar between the two systems, with Nine Mile Reservoir concentrations slightly higher. Although minimum dissolved oxygen concentrations observed at the dams are lower for Nine Mile Reservoir than Palisades Lake, it must be noted that this could be related to the greater depth of Nine Mile Reservoir than Palisades Lake. At almost every depth, when compared directly, Nine Mile Reservoir maintains a comparable and sometimes higher dissolved oxygen profile than Palisades Lake (Figure 3.17). This comparison holds down to the maximum depth (7.8 meters) for which data is available in both systems. Low dissolved oxygen at greater depths in Nine Mile Reservoir can not be directly compared with Palisades. Low dissolved oxygen in Nine Mile Reservoir is isolated to the sediment-water interface, a pattern that is exhibited by most reservoirs. The fact that the low dissolved oxygen profiles do not extend upward into the water column suggests that the hypolimnetic oxygen demand in Nine Mile Reservoir is not excessive.

Average inflow nitrogen concentrations to Nine Mile Reservoir, including the springs that discharge to the reservoir, represent the greatest difference between the two systems, with concentrations in Nine Mile Reservoir inflows observed to be nearly 4 times greater than those observed in Six Mile Creek downstream of the diversion to Nine Mile Reservoir.

Table 3.26 Summary of Comparative Data Between Palisades Lake and Nine Mile Reservoir

	Palisades at Dam 1999–2006	Nine Mile 1999–2006			Six Mile at San Pitch 2001–2006	Springs at Discharge 2006
		Inflow	At Dam	Mid-reservoir		
Alkalinity (mg/L)						
Average	183	--	269	--	271	--
Max	216	--	364	--	405	--
Dissolved Oxygen (mg/L)						
Average	8.07	7.53	8.84	9.82	9.40	6.79
Min	2.36	5.85	0.28	1.37	4.50	6.36
% Exceed	5%	0%	14%	5%	0%	0%
Dissolved Oxygen Sat (%)						
Average	105.3%	90.9%	118 %	132 %	94 %	--
Max	163.0%	113.9%	194 %	196 %	112 %	--
% Exceed	47%	13%	64%	77%	5%	--
NO2+NO3 (mg/L)						
Average	0.21	3.41	0.33	0.32	0.95	2.26
Max	0.57	6.52	2.13	1.18	2.80	6.70
% Exceed	0%	0%	0%	--	--	17%
pH						
Average	8.60	8.25	9.01	9.10	8.41	8.11
Max	9.10	8.73	10.07	9.86	8.97	8.44
% Exceed	13%	0%	54%	60%	0%	0%
Total Phosphorus (mg/L)						
Average	0.02	0.030	0.010	0.020	0.02	0.010
Max	0.14	0.261	0.068	0.257	0.07	0.016
% Exceed	24%	20%	6%	10%	13%	0%
Temperature (°C)						
Average	18.40	18.33	20.04	20.22	10.21	18.06
Max	24.25	26.41	25.8	24.36	21.81	22.3
% Exceed	32%	33%	20%	14%	--	--
Salinity (ppt)						
Average	0.20	0.43	0.42	0.39	0.35	--
Max	0.24	0.68	0.70	0.50	0.79	--

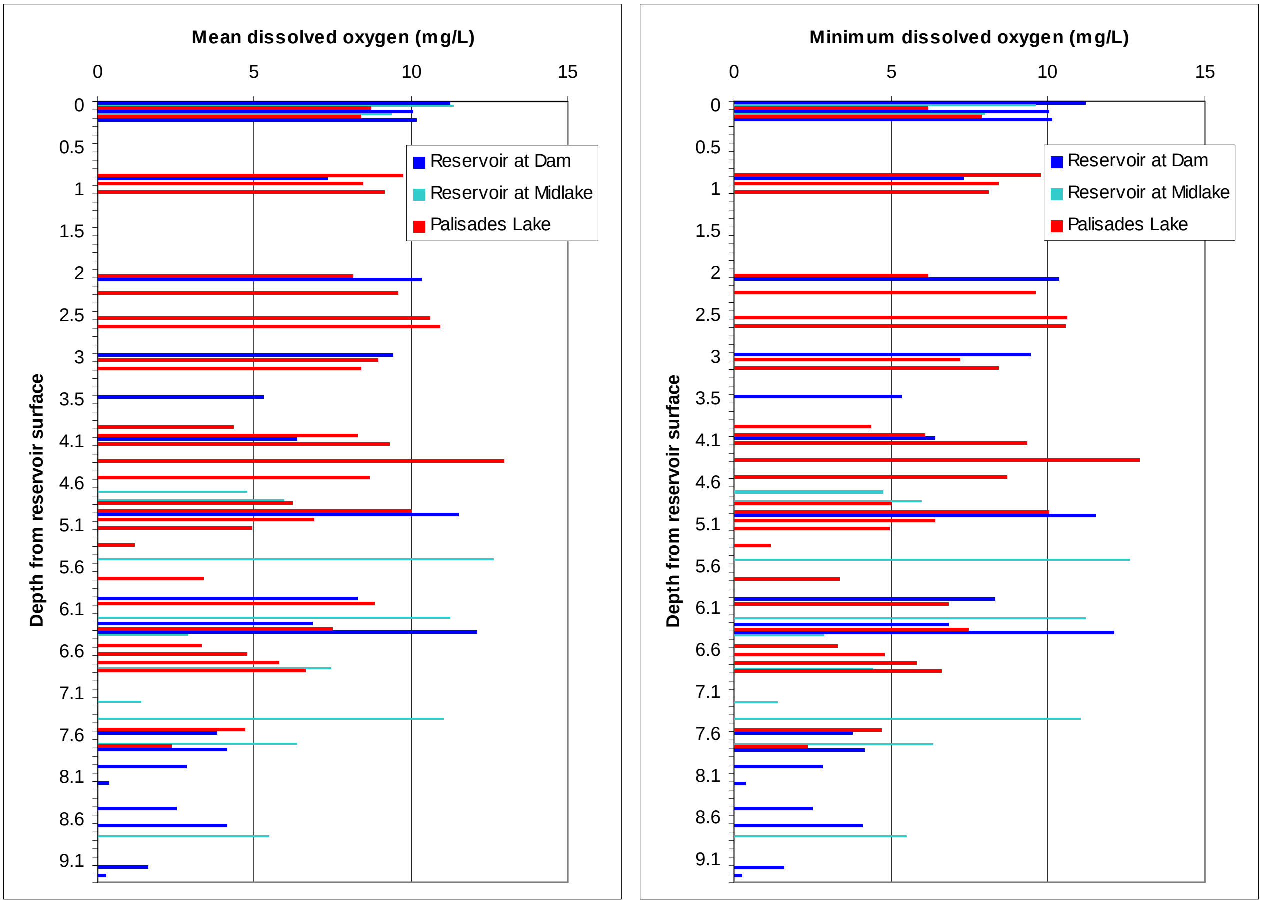


Figure 3.17 Dissolved oxygen profiles in Nine Mile Reservoir and Palisades Lake for Mean and Minimum Dissolved Oxygen.

While maximum pH values observed at the dams show violations of water quality criteria (9.0) occurring in both cases, the magnitude of the exceedance observed in Palisades Lake is 10 times lower than that for Nine Mile Reservoir (0.1 units and 1.1 units, respectively). Given the differences soil pH surrounding the two reservoirs the greater magnitude of pH exceedance is most likely the result of both more alkaline soils on the southwest portion of Nine Mile Reservoir.

Average and maximum total phosphorus concentrations are similar in both systems, while average and maximum concentrations in Nine Mile Reservoir are at the dams 2 times lower than those observed at Palisades Lake. However, the highest phosphorus value in the dataset was observed at the Mid-reservoir Site in Nine Mile.

Average salinity observed in Nine Mile Reservoir is approximately 2 times higher than that observed in Palisades Lake and maximum salinity is approximately 3 times higher. This is likely due in part to the high-alkaline soils present in a portion of Nine Mile Reservoir.

Depth integrated data are available for the Dam Site at Palisades Lake and show similar trends as observed in Nine Mile with the exception that pH exceedances are minor and dissolved oxygen levels do not drop as low as observed in Nine Mile Reservoir.

3.5.5.3 Implications for Nine Mile Reservoir impairment status

The differences in management between Palisades Lake and Nine Mile Reservoir do not allow a direct comparison of water quality characteristics on a seasonal basis. However, the general trends identified in this comparison demonstrate that soil alkalinity in Nine Mile Reservoir and the immediate watershed area contributes to elevated pH levels and pH criteria exceedances in the reservoir. In addition, this comparison indicates that dissolved oxygen profiles are generally slightly higher in Nine Mile Reservoir than in Palisades Lake. This comparison corresponds to lower nutrient concentrations, on average, in Nine Mile Reservoir when compared with Palisades Lake. Neither system exhibits routine exceedances of the water quality criteria established for dissolved oxygen nor the threshold identified for total phosphorus in reservoirs. Since Palisades Lake is not listed as impaired for dissolved oxygen and total phosphorus, based on the comparison between the two systems Nine Mile Reservoir should be removed from the 303(d) list for the low dissolved oxygen impairment.

3.5.6 IMPAIRMENT ADJUSTMENTS

Up to this point, all of the evidence presented indicates that Nine Mile Reservoir is in full support status for all of the beneficial uses designated for the water body. Since this determination is made on the basis of exceedances of physical and chemical water quality parameters, the State of Utah allows for the initial support status determination to be modified based on biological indicators of water quality. For reservoirs, this includes 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. In order to complete a comprehensive review of the support status of Nine Mile Reservoir, these criteria are evaluated in the following sections.

3.5.6.1 Trophic State Index (TSI)

The health and support status of a water body can be assessed using a TSI, a measurement of the biological productivity or growth potential of a body of water. The basis for trophic state classification is algal biomass (estimation of how much algae is present in the water body). The calculation of a TSI generally includes the relationship between chlorophyll (the green pigment in algae, where chlorophyll *a* is used as a surrogate measure of algal biomass), transparency using Secchi depth measurements, and total phosphorus (commonly the nutrient in shortest supply for algal growth) as follows (Carlson and Simpson 1996):

- Chlorophyll *a*: $TSI_{CHL} = 9.81 \ln(\text{Chl a}) + 30.6$
- Secchi depth: $TSI_{SD} = 60 - 14.41 \ln(\text{SD})$
- Total Phosphorus: $TSI_{TP} = 14.42 \ln(\text{TP}) + 4.15$

Waterbodies with very low TSI values (less than 30) are generally transparent, have low algal population densities, and have adequate dissolved oxygen throughout the water column. Waterbodies with these characteristics are generally supportive of cold-water fisheries and are identified as **oligotrophic**.

Waterbodies with low to midrange TSI values (40-50) are moderately clear, and have an increasing chance of hypolimnetic anoxia in summer. Waterbodies with these characteristics are generally supportive of warm water fisheries and are identified as **mesotrophic**.

Waterbodies with midrange TSI values (50–70) commonly experience more turbidity (the water is not as clear) and higher algal population densities than oligotrophic waterbodies. These waterbodies often exhibit low dissolved oxygen levels in mid- to late-summer, with the most extreme conditions observed in the hypolimnetic (deeper) water column. Waterbodies with these characteristics often experience some macrophyte problems (excessive growth) and are generally supportive of warm water fisheries only. These waterbodies are identified as being **eutrophic**.

Waterbodies with high TSI values (70 and greater) are generally observed to have heavy algal blooms, dense macrophyte growth, and extensive dissolved oxygen problems that often occur throughout the water column. Fish kills are often common and recreation is limited under such conditions. Fish populations are generally confined to rough fish species. Such waterbodies are identified as **hypereutrophic**.

Table 3.27 identifies generally accepted trophic state values derived from this relationship. In most cases, the greater the TSI value a water body has, based on collected data, the more eutrophic the water body is said to be.

Table 3.27 TSI Values and Status Indicators

TSI	Trophic Status and Water Quality Indicators
< 30	Oligotrophic; clear water; high DO throughout the year in the entire hypolimnion.
30–40	Oligotrophic; clear water; possible periods of limited hypolimnetic anoxia (DO =0).
40–50	Mesotrophic; moderately clear water; increasing chance of hypolimnetic anoxia in summer; cold water fisheries “threatened”; supportive of warm water fisheries.
50–60	Mildly eutrophic; decreased transparency; anoxic hypolimnion; macrophyte problems; generally supportive of warm water fisheries only.
60–70	Blue-green algae dominance; scums possible; extensive macrophyte problems.
70–80	Heavy algal blooms possible throughout summer; dense macrophyte beds; hypereutrophic.
> 80	Algal scums; summer fish kills; few macrophytes due to algal shading; rough fish dominance.
Source: From Carlson and Simpson, 1996.	

The trophic scale outlined in Table 3.27 illustrates these general classifications, as well as the midrange conditions that occur between each major category. However, each water body is unique and will exhibit site-specific characteristics based on the water quality conditions identified within the lake or reservoir and over specific time periods, seasons, or water flow conditions. The identification of TSI values for a specific waterbody allows a general classification and may provide insight into overall water quality trends and seasonality.

Summer TSI values for Nine Mile Reservoir have been calculated using the data available for chlorophyll *a* concentrations, Secchi depth, and total phosphorus concentrations. The resulting values are displayed in Figures 3.18 and 3.19. Mean TSI values for Nine Mile Reservoir are listed in Table 3.28.

Results of the TSI evaluation for Nine Mile Reservoir indicate that the reservoir is generally mesotrophic with mean TSI values ranging from 29 (chl *a* TSI) at mid-reservoir to 45 (Secchi depth TSI) at the Dam Site. Recently, TSI values at the Dam Site have been improving while results at the Mid-reservoir Site have been more varied during the sampling period but are indicative of improving conditions.

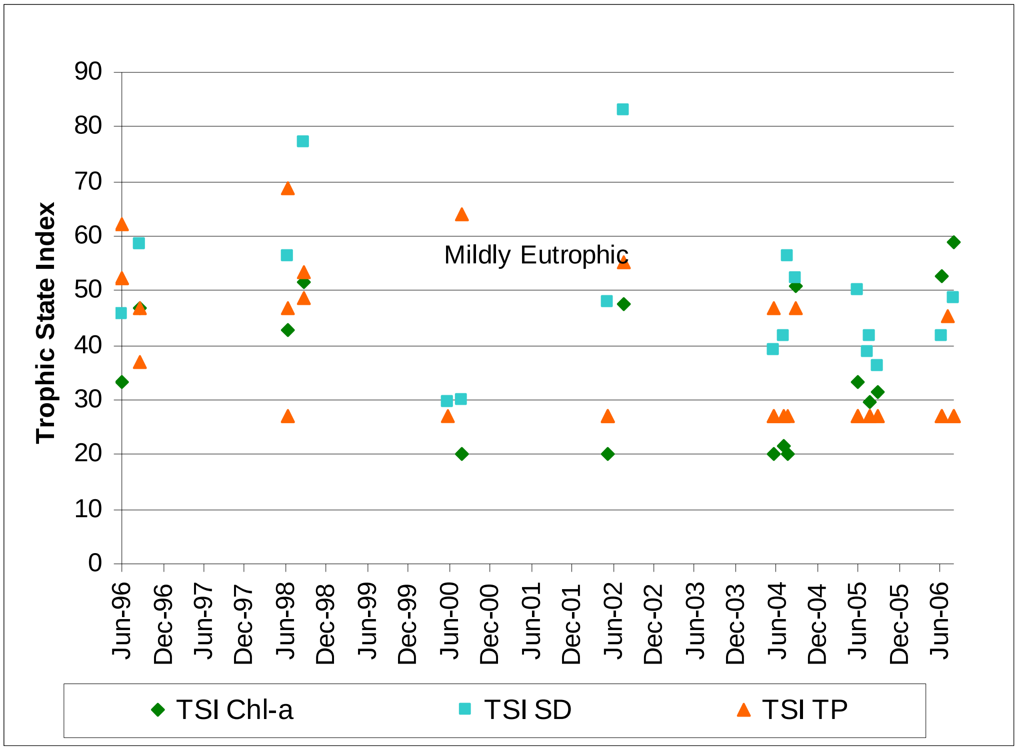


Figure 3.18 Trophic state index trend data for Dam Site

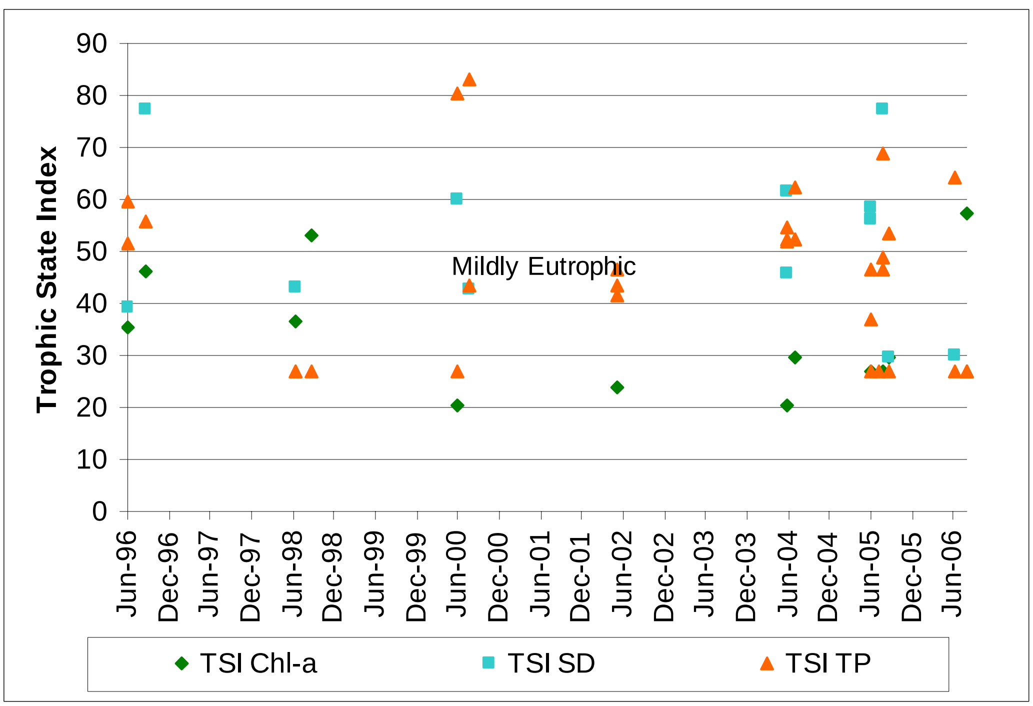


Figure 3.19 Trophic state index trend data for Mid-reservoir Site.

Table 3.28 Summary of Current (1999–2006) TSI Data in Nine Mile Reservoir.

Site Name	Mean Chlorophyll *a* TSI	Mean Secchi Depth TSI	Mean Total Phosphorus TSI
Reservoir at dam	33.9	45.5	30.6
Mid-reservoir	29.4	41.3	34.2

Determining the relationship between TSI values calculated for a specific water body is also helpful in identifying factors that limit algal biomass and/or affect the measured water quality parameters. Although every water body is unique, a number of common relationships between Secchi depth, chlorophyll *a*, and total phosphorus have been identified (Carlson 1992). The routine occurrence of lower chlorophyll *a* TSI than Secchi depth TSI, as shown in Figures 3.18 and 3.19, indicates reduced transparency from non-algal factors including clay or dissolved organic matter (Carlson 1992). In Nine Mile Reservoir, this could indicate turbidity associated with carbonate alkalinity. The data show that chlorophyll *a* TSI values and total phosphorus levels rarely exceed mildly eutrophic levels. The majority of TSI values above the mesotrophic condition are attributed to Secchi depth readings which are indicative of turbidity interference associated with alkalinity.

3.5.6.2 Fish Kills

There have been no reported fish kills in Nine Mile Reservoir (UDWQ 2007). The reservoir is stocked by DWR annually with rainbow trout and tiger trout (rainbow/brook trout hybrid). Fishing usage within the reservoir has been reported as light.

3.5.6.3 Phytoplankton Composition

The presence of blue-green algae, or cyanobacteria, in the phytoplankton community has been associated with the occurrence of toxins and mortality in local animal populations (Sabater and Admiraal 2005). Although cyanobacteria may be of low toxicity, cyanotoxins can become highly concentrated in the environment or through bioaccumulation where cyanobacterial overgrowth occurs. The introduction and/or overgrowth of cyanobacterial species is a potential hazard to water quality and the Nine Mile Reservoir aquatic ecosystem. Cyanobacteria can dominate nitrogen-limited systems due to their ability to fix atmospheric nitrogen. As a result, cyanobacteria can increase where low nitrogen limits the growth of other algal species (Sharpley et al. 1984 and 1995; Tiessen 1995).

The relative densities of algal species and diversity of the algal community both serve as surrogate measures of water quality by identifying overall species diversity, excessive algal growth or eutrophication, and the presence and relative abundance of toxic blue-green algae.

This assessment is based on phytoplankton samples collected from Nine Mile Reservoir in 2000, 2002, and 2004. Species abundances were measured using counts for periphyton and number per liter for phytoplankton. Detailed plankton data are available for the Dam Site at Nine Mile Reservoir for August 9, 2000, August 8, 2002, and August 10, 2004 (Rushforth and Rushforth 2001, Rushforth and Rushforth 2003, Rushforth and Rushforth 2005). Algal taxa present at these times were identified and grouped by taxon to show green algae (chlorophyta), blue-green algae (cyanophyta), diatoms (bacillariophyta), and others.

In 2000 and 2002, green algae dominated at 71.6% and 89.7% respectively of the total algal population. Diatoms represented a much smaller population segment at 0.8% and 9.8% respectively of the total. The 2004 sampling also proved green algae to be the dominant population, representing 61.5% of the total algal population. Diatom populations were again substantially smaller than the green algae population, representing 27.9% of the total. Blue-green algae were not detected in 2000 or 2004. Small populations of blue-green algae were found in 2004 representing 5.4% of the total phytoplankton population.

3.5.7 SUPPORT STATUS SUMMARY

There have been no observed exceedances of the dissolved oxygen criteria established by the State of Utah in Nine Mile Reservoir since 1999. More than 50% of the water column meets dissolved oxygen criteria of greater than 4.0 mg/L during all months at both sites; therefore the reservoir is in full support status for the cold water fishery–designated beneficial use, based on the dissolved oxygen criteria. This conclusion is supported by an analysis of nutrient and chlorophyll *a* data available for Nine Mile Reservoir.

Current mean and median total phosphorus concentrations are below the threshold established by the State of Utah. This threshold of 0.025 mg/L is rarely exceeded in Nine Mile Reservoir, with more than half of the data points available for the reservoir recorded as "nondetect." Exceedances appear to be associated primarily with low reservoir water level during which time phosphorus in the sediment is more likely to be suspended throughout the water column. Since no conservation pool has been established for this reservoir, the management of the reservoir level is not negotiable. Chlorophyll *a* values are also well below the indicator values of 10 µg/L identified in the literature of being protective of cold water fisheries and recreational uses.

Trend data for total phosphorus concentration, chlorophyll *a*, and Secchi depth indicate that water quality in the reservoir has been improving since 2000, with the exception of one high total phosphorus concentration identified in the summer of 2006.

Dissolved oxygen saturation data do show routine exceedances of the 110% saturation criteria established for dissolved gases; however the majority of these exceedances occurred at depths greater than 1 meter for which raw data had not been corrected for hydrostatic pressure. When these data are corrected, mean and median dissolved oxygen saturation for Nine Mile Reservoir are below the 110% criteria. Routine exceedances of 110% saturation at the surface of Nine Mile Reservoir could be indicative of diurnal fluctuations in temperature and oxygen solubility. High dissolved oxygen saturation values could also indicate in-reservoir algal growth, however chlorophyll *a* data do not support this interpretation.

Elevated pH levels in Nine Mile Reservoir are associated with naturally alkaline soils in the watershed that extend below the reservoir. This natural condition results in the exceedance of the pH criteria established for cold water fisheries by the State of Utah. The reservoir also experiences elevated temperature throughout the summer. However, this condition has been associated with a recent drought throughout the state. UDWQ has determined that this explains the temperature exceedances observed in the reservoir. Nine Mile Reservoir is not listed as impaired for temperature on the 2006 State of Utah 303(d) list of impaired waters.

A comparison between Nine Mile Reservoir and Palisades Lake, both of which receive inflow from Six Mile Creek, indicates that pH and alkalinity are significantly higher in Nine Mile Reservoir than in Palisades Lake, providing another line of evidence that high pH in Nine Mile results from the alkaline soils in the surrounding area. Mean total phosphorus and dissolved oxygen are similar between the two systems, based on a detailed water column analysis, indicating that Nine Mile Reservoir should not be listed as impaired for this water quality parameter. Water column dissolved oxygen values are comparable between the two reservoirs at specific depths and often lower in Palisades Lake. The lowest dissolved oxygen measurement in Nine Mile Reservoir is at a depth lower than the maximum depth for Palisades Lake making it difficult to compare the two systems at such depths. It is expected that a larger hypolimnion would form in a deeper reservoir and stratification would take place for a longer period of time resulting in lower dissolved oxygen expected at the sediment-water interface.

Analysis of the TSI, fishery, and phytoplankton composition for Nine Mile Reservoir add further support to the conclusion that Nine Mile is not impaired for low dissolved oxygen or elevated total phosphorus. The reservoir is generally mesotrophic. Occurrences of reduced turbidity measured in terms of Secchi depth generally indicate a non-algal source of light interference associated with the high-alkaline water in the reservoir. There have been no documented fish kills in the reservoir and blue-green algae species are not prevalent.

4 WATERSHED AND RESERVOIR MODELING

The watershed and reservoir modeling approach chosen for Nine Mile Reservoir was used to predict nutrient concentrations in Six Mile Creek, nutrient loads from the Nine Mile Reservoir watershed, and reservoir water quality under average conditions. The Soil and Water Assessment Tool (SWAT) model was used to simulate hydrologic and nutrient load output from the watershed (Nietsch 2000) and the BATHTUB reservoir model (Walker 1999) was used to simulate water quality in Nine Mile Reservoir. The linked SWAT and BATHTUB modeling scheme provides a systematic method for modeling nutrient sources, transport, delivery, and assimilation in a watershed-reservoir system.

4.1 WATERSHED MODEL: SOIL AND WATER ASSESSMENT TOOL (SWAT)

The SWAT model was used to simulate hydrologic and nutrient load output from the watershed. Multiple SWAT simulations were executed in order to account for the variability in annual and seasonal climatic patterns as well as input for reservoir management simulations which have been completed with the BATHTUB model. The SWAT simulations were paired with simulations of different reservoir management patterns (Figure 4.1) using the BATHTUB model. The years 1997 through 2006 were used to estimate flow and runoff patterns during an average hydrologic year. The SWAT simulation output was validated with existing water quality monitoring data which had been collected within Six Mile Creek.

4.1.1 GENERAL MODEL DESCRIPTION

The USDA Agriculture Research Station (USDA ARS) developed SWAT to predict the effects of management practices on water, sediment, nutrient, and pesticide yields at the watershed scale. The tool uses a GIS environment to subdivide watersheds into smaller, spatially linked units with Digital Elevation Models (DEM). To further divide subwatersheds into hydrologic response units (HRUs), the tool breaks units by land use, management practices, and soil-type GIS coverages. An HRU is not a spatial subdivision but rather a total area within a subwatershed that possesses similar land uses and soils. Within SWAT, all HRUs are assumed to be homogenous. Moreover, they simplify model simulations by combining land uses and soil types that overlie each other in the GIS environment.

4.1.1.1 Model Components and Operation

The SWAT modeling tool incorporates climatic and physical watershed data and stream reach routing to simulate hydrologic dynamics, crop growth, and nutrient dynamics. Overall, the SWAT modeling tool provides the modeling environment necessary to simulate groundwater and surface water hydrology and water quality at the watershed scale (Figure 4.1).

The model makes use of long-term continuous time period simulations using readily available data for inputs. These data inputs include regional hydrology, DEMs, climatic data, soils, and land uses. Most of these data are available from regional or national natural-resource agencies without cost. Figure 4.1 summarizes the physical processes that SWAT simulates. The tool simulates the hydrology of the watershed using several different physical processes including ET and canopy storage for water that is intercepted by vegetation, infiltration, and redistribution. The tool uses rainfall amounts to calculate surface runoff volumes, infiltration, and peak runoff rates for each HRU. The model is capable of using either the STATSGO or the Soil Survey Geographic (SSURGO) database for soils data. The model allows up to 10 soil layers where infiltration and water holding capacity, among other things, may be modified. Water held within the soil profile is moved through the matrix by the storage routing method.

Not all areas within the state have complete SSURGO data coverage at this time, so STATSGO data is applied. Land use and land cover (LULC) information is also used for a data layer. The LULC coverage is overlain with the soil GIS layer to facilitate HRU development for the application of the physical-based equations applied throughout the modeled watershed.

The model accounts for both saturated and unsaturated flows. Saturated flow is driven by gravity and the movement is characterized by a storage routing method. The latter calculates the amount of soil water percolating to an underlying soil layer on a given day. Water in excess of the permanent wilting point, or soil field capacity, is available for plant growth or infiltration within the soil profile. For unsaturated flow, movement occurs in any direction based on energy gradients from areas of high to low water content. Only saturated flow is simulated; however, water consumed by the plant during growth is simulated indirectly by the ET process associated with the plants.

The model relies on climatic data for computer simulations and makes use of many different sources of climatic data in equations associated with physical processes within the watershed. The model also has a built-in weather generator that employs a network of weather stations throughout the country to develop a climatic record. This climatic record is based on averaged values, which demonstrate weather extremes that may have occurred within the watershed being modeled during the simulation period.

Two daily climatic datasets (including temperature and precipitation), in most cases, should be developed using local weather station data. The model will associate the local climate station dataset to each subbasin within the watershed boundary and apply the climate data for the simulation. During the simulations, any missing climate data are estimated by the model to provide for a complete dataset. Other climate data required by the model, such as wind speed, relative humidity, and daily solar radiation, are usually simulated by the model. On rare occasions when actual measured data are available on a daily time step, these data are used in lieu of simulated data.

The model has two methods for infiltration and runoff. The first method is the Green-Ampt method, where water infiltration occurs through a wetted front routine. This method requires subhourly precipitation data which is not available in this watershed and will therefore not be discussed further. The other runoff method is the SCS curve number (CN), which is based on a rainfall-runoff relationship where overland flow will not occur until all depressional storage (surface storage, canopy interception, and infiltration) has occurred. The equation also looks at soil permeability, land use, and antecedent soil moisture conditions to determine runoff. The runoff rate is dependant upon empirical values that have been developed across the U.S. for cover types associated with land uses present within the watershed. The CN influences the runoff values and is accounted for by a CN value applied within model parameter settings. This number is set initially within the model but may be changed to adjust runoff values during model simulations.

The SWAT model also simulates shallow and deep groundwater aquifers. Shallow aquifers contribute flow to the stream reach in the watershed and also reinfiltrate water into the soil profile. The remaining infiltrated water may also be pumped out or may recharge the deeper aquifer. This aquifer is confined and contributes water outside of the watershed. Waters of the deep confined aquifer that are not pumped for irrigation purposes are considered lost to the watershed.

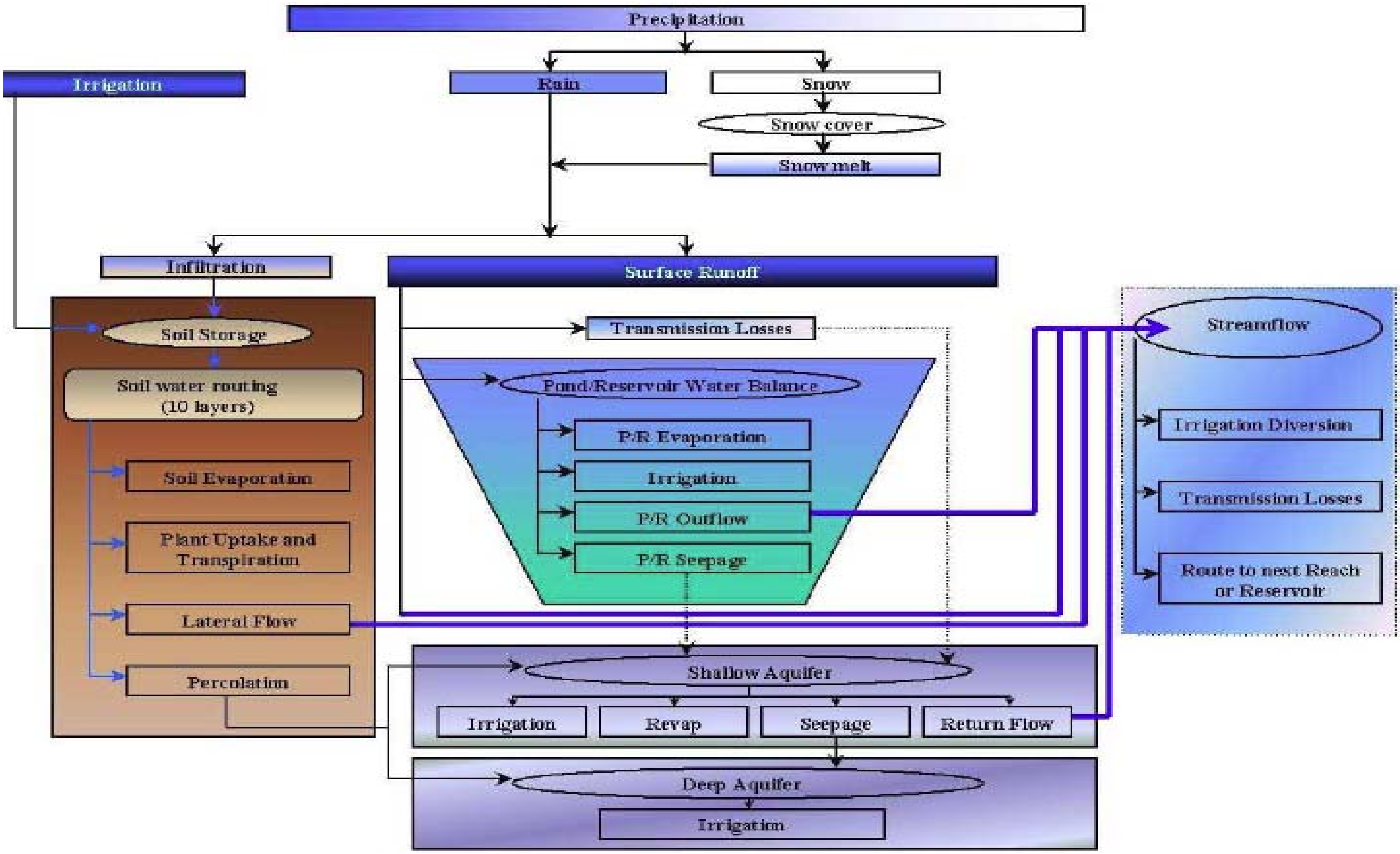


Figure 4.1. SWAT model schematic of water routing and processes (Neitsch 2002).

To simulate erosion and sediment yield, SWAT uses the Modified Universal Soil Loss Equation (MUSLE), which employs the amount of runoff derived from the runoff methods (listed above) to calculate sediment yield. The sediment is delivered to the surface water system by overland flow. The model uses two versions of the kinematic wave approximation (variable storage and Muskingum approximation) to route waters through the stream channels. In-stream sediment transport and channel erosion are also included. In-stream water quality processes are modeled using built-in modified QUAL2E mathematical methods.

For nutrient simulation processes, SWAT models the water flow through the natural system to determine the amount of nutrients transported from one source to another. For nitrogen simulation, the basic nitrogen cycle and transformations are used. The SWAT tool monitors five different pools of nitrogen in the soil (two inorganic and three organic). The loading function estimates daily organic nitrogen (N) loss based on the organic N concentration in the uppermost layer of soil, the sediment yield, and a N-enrichment ratio. Soluble and organic phosphorus are also removed by transport with the water movement described above. Soluble phosphorus (P) runoff is calculated using the solution P values in the upper 10 mm present in the soil, the runoff volume, a soil-partitioning factor, as well as an enrichment ratio. The tool monitors six different pools of phosphorus in the soil (three inorganic and three organic) and these pools are further divided by rate of decay and mineralization into active and labile pools. Nutrient loads and water flow rates will be used as inputs into a one-dimensional reservoir model (Neitsch et al. 2002).

4.1.2 Model Development for Nine Mile Reservoir Watershed

A watershed model was produced for the Nine Mile Reservoir watershed using SWAT 2005. Numerous steps are involved in the process of deriving and building the spatial model as input into the SWAT model. A GIS interface is employed within SWAT to achieve this task. The initial setup of the watershed included the processing of DEMs, hydrography, soils, LULC, as well as connecting local climatic data to the watershed.

4.1.2.1 Digital Elevation Data for the Nine Mile Reservoir Watershed

The elevation gradient for the Nine Mile Reservoir watershed was obtained from the USGS National Elevation Dataset (NED) website (http://ned.usgs.gov/). The NED is a 1:24,000-scale DEM for the conterminous U.S.; it has a geographic projection with a one-arc second resolution and elevation units in meters. The horizontal datum is NAD83, with a vertical datum of NAVD88. The coverage is a continuous grid and overlays the entire watershed.

4.1.2.2 Hydrology Data for Nine Mile Reservoir Watershed

The Nine Mile Reservoir watershed is located in Sanpete County, within central Utah, about 90 miles south of Salt Lake City. The Hydrologic Unit Code (HUC) #16030004 is designated for the San Pitch River watershed as defined by the United States Geological Survey (USGS), of which the Six Mile Creek and Nine Mile Reservoir watersheds are part of. The Nine Mile Reservoir watershed is located in the western margins of the Six Mile watershed. With the construction of the Sterling Irrigation Diversion located near Sterling, Utah, a significant portion of the Six Mile Creek flow can be diverted directly to Highland Canal for delivery and storage in the Nine Mile Reservoir for use as irrigation water. The SWAT model for the Nine Mile Reservoir watershed was developed with the knowledge of the trans-basin diversion. The modeled watershed includes the Six Mile watershed as well as the much smaller Nine Mile Reservoir watershed. The trans-basin diversion occurs from approximately March to the end of May with one-half of the Six Mile Creek flow diverted into the Highland Canal for delivery to the Nine Mile Reservoir. The remaining Six Mile Creek flow continues through the watershed to the San Pitch River or is diverted into the Palisades Lake. No historical measurement data is available for any of the diversions. Only anecdotal information from local water resource officials is available.

Hydrology for the Nine Mile Reservoir watershed was obtained from the USGS National Hydrography (NHD) website (http://nhd.usgs.gov/data.html). Within the NHD, surface water reaches link the surface water drainage network. The NHD is based on a digital line graph (DLG) hydrography, with reach-related information from the EPA Reach File Version 3.0 (RF3). Included within the NHD are Six Mile Creek and Nine Mile Reservoir.

4.1.2.3 LULC and Soils Data for the Nine Mile Reservoir Watershed

The Southwest Regional Gap Analysis Project (SWReGAP) LULC dataset was originally used in the setup of the Nine Mile Reservoir watershed model. Coverage for SWReGAP is on a regional, multiple-state scale (i.e., Arizona, Colorado, Nevada, New Mexico, and Utah). The project focuses on mapping land cover for large geographic areas (Lowry et al. 2005). The SWReGAP LULC dataset, though very detailed in land coverage description, is not compatible with SWAT. The SWReGAP land use descriptions were therefore converted to Multi-Resolution Land Characteristics Consortium (MRLC) National Land Cover Dataset (NLCD) descriptions. These land cover data are based on land cover classes including various forest types, urban land uses, surface water, wetlands, and agricultural lands, among others.

Table 4.1 Watershed Land Use and Area Breakdown Used for Load Calculations

	Six Mile Watershed		Nine Mile Watershed		Total Watershed Combined Acreage	
Land Use	**Area (ha)**	**Area %**	**Area (ha)**	**Area %**	**Area (ha)**	**Area %**
Urban	56.9	0.7%	29.5	1.4%	86.4	0.8%
Pasture	208.7	2.4%	173.0	8.1%	381.7	3.5%
Forest (deciduous)	3714.0	42.0%	421.0	19.7%	4135.0	37.7%
Forest (evergreen)	3166.0	35.8%	1065.1	49.8%	4231.1	38.5%
Range (brush)	599.8	6.8%	256.8	12.0%	856.6	7.8%
Range (grass)	1063.0	12.0%	182.2	8.5%	1245.2	11.3%
Wetland	31.6	0.4%	13.3	0.6%	44.9	0.4%
Total	8840.0	100.0%	2140.9	100.0%	10980.9	100.0%

The SWAT model uses MRLC NLCD land cover descriptions to assign plant growth properties and land runoff potential based on a built-in database of physical properties associated with each of the land uses. Together with the STATSGO data on soils coverage properties HRUs for the watershed were calculated by setting a threshold level of minor land-use areas with land-use areas less than the threshold level being ignored, and reapportioning it among the major land uses and soil types. The default values for the threshold are usually set at 10% for land use and 20% for soil type. This means that any land use taking place in an area of less than 10% within the watershed would be reassigned by the model to the most similar land use type. The same would occur for soil coverage, which has an area threshold of less than 20% within the watershed. Because of the detailed coverage supplied by the SWReGAP data, the threshold levels for the HRU determination were set at 2% for land use and 4% for soils. This allowed for a more detailed assessment associated with land use near Six Mile Creek and Nine Mile watershed for the application of irrigation events and grazing activity. Land uses assigned within the model, including acreage and percent area within the watershed, are listed in Table 4.1. Forested lands and rangelands make up approximately 76% and 19% of the watershed, respectively.

4.1.2.4 Management Practices for the Nine Mile Reservoir Watershed

The SWAT model accommodates input for management practices associated with land uses. These practices are imbedded in the model at the HRU level, facilitating input of spatial scale land management data and, in turn, facilitating output results that may be evaluated within specific areas within the watershed.

The grazing of cattle and sheep within the watershed occurs throughout the summer growing season. Though the boundaries of the grazing allotments are known in the watershed, what is not known is the specific number of cattle and sheep that are present within each subbasin for any specified amount of time. The SWAT model allows for the inclusion of grazing animals within a subbasin but evaluates the grazing within each subbasin based upon daily food uptake, animal pressure on the range, and manure deposition. Other grazing controls also allow for the setting of grazing days within a subbasin along with the establishment of a crop residual amount that precludes the animals from overgrazing the grassland to levels below actual growth potential. This factor forces the model to eliminate grazing from any subbasin before simulated overgrazing occurs. The average grazing animal parameters have been set as follows:

	Cattle Grazing	Sheep Grazing
Daily Forage Uptake(dry weight)	80.1 lb/ac/day	28.8 lb/ac/day
Grazing Time Limit/subbasin	45 days	45 days
Trampling impact from hooves (dry weight)	0.9 lb/ac/day	0.29 lb/ac/day
Manure deposition (dry weight)	0.22 lb/ac/day	0.06 lb/ac/day
Biomass Residual	356 lb/acre	356 lb/acre

The management inputs were scheduled within the simulation by using heat units (Neitsch 2002). The heat units are based upon the fact that any crop needs specific temperatures to start production within a growing period. Any temperature value above the baseline minimum temperature for a crop goes into the plant for growth. Specific management practices can be scheduled in SWAT based upon a percentage of the total heat units required for the crop to grow and be harvested, with a value of 1 for when growth is complete for the year. Based upon that information, irrigation events were scheduled at the fractional values 0.3 and 0.75 heat units for the crop while grazing was scheduled at a fraction value of 0.4 heat units.

Table 4.2 demonstrates locations within the watershed where irrigation water have been applied as well as the amount of water applied. The irrigation water is applied to specific HRUs located within the subbassin to limit the water application to defined land use areas. Irrigation of individual fields or exclusive areas within an HRU is not possible within SWAT. Water applied to an HRU is applied to the entire HRU.

Table 4.2 Irrigation of Agricultural Lands of Six Mile and Nine Mile Watersheds

Subbasin	HRU	Area (km^2)	Acres	Input(mm)	Input (in)	Volume (ac-ft)
70	217	0.50	123.6	18.82	0.74	7.62
95	295	0.06	14.83	3.05	0.12	0.15
97	302	0.02	4.94	8.21	0.32	0.13
99	308	0.78	192.74	11.18	0.44	7.07
100	311	0.25	61.77	34.10	1.34	6.90
102	316	0.01	2.47	1.03	0.04	0.008
102	317	0.01	2.47	53.68	2.11	0.43
128	398	0.08	19.77	33.82	1.33	2.19
138	426	1.04	256.99	44.62	1.75	37.48
187	568	0.19	46.95	44.62	1.75	6.85
Total	**--**	**2.94**	**726.53**	**253.13**	**9.94**	**68.83**

4.1.2.5 Climatic Data Inputs for the Nine Mile Reservoir Watershed

Climatic data for the watershed are required by SWAT. A built-in weather generator within the model generates data by using climatic averages from nearby climatic stations. Data generated from stations located in the watershed, or within close proximity, more closely represent existing watershed conditions than data generated elsewhere. The Nine Mile Reservoir watershed is in an isolated area with no climatic stations. The SWAT model assigned the New Harmony climatic station using a "nearest subbasin-centroid" algorithm. In situations where no climatic stations are present within the watershed being studied, interpolating between datasets from two nearby climatic stations is ideal. However, in the case of the Nine Mile Reservoir watershed, only one nearby climatic station is present. Minimum and maximum daily temperatures and precipitation levels from the New Harmony climatic station were used as significant driving factors in the model.

4.1.3 Simulation Period for the Nine Mile Reservoir Watershed

For the purposes of this analysis, the SWAT 2005 model simulation period was October 1995 through September 2006 (water year 1996 through water year 2006). The first water year of the simulation output is considered a model "warm-up" period, with water levels and content within the hydrologic system reaching equilibrium by filling the soil profile with water, supplying water to the reservoir, and starting the physical processes occurring within the watershed. Data from 1995 is therefore excluded. Flow and nutrient concentrations from the SWAT model are used to evaluate model output for the Nine Mile Reservoir watershed. Output results for SWAT were summarized for the May–October period, in order to capture the critical season for potential algal growth.

4.2 Reservoir Model: BATHTUB

4.2.1 General Model Description

The BATHTUB reservoir model was developed by the U.S. Army Corps of Engineers (USACE) as a sophisticated empirical model for predicting eutrophication in reservoirs. The model can be used to predict nutrient concentrations, chlorophyll *a*, Secchi depth (transparency), and other eutrophication indices in a spatially segmented reservoir under steady-state conditions.

Model inputs include reservoir morphometry (mean depth, length, width, mixed-layer depth), hydraulic connectivity (between reservoir segments and tributaries), tributary water quality (total nutrients, dissolved nutrients, and flow), and climatic parameters (precipitation and ET). The model uses empirical equations for physical processes—advective transport, diffusive transport, and nutrient sedimentation—to predict nutrient concentrations in reservoir water quality.

Within the BATHTUB model, various empirical models predict total phosphorus, total nitrogen, chlorophyll *a* concentrations, and Secchi depth. The models summarized in Table 4.3 were found to best fit Nine Mile Reservoir system conditions.

Table 4.3 Empirical Models Selected for Reservoir BATHTUB Model of Nine Mile Reservoir

Parameter	Model selected	Justification
Conservative substance	Not computed	Default and no data
Total phosphorus	2^{nd} Order, Available P	Default
Total nitrogen	2^{nd} Order, Available N	Default
Chlorophyll-a	P, N, Light, T	Reservoir has low turbidity except during algal blooms. N and P are possibly co-limiting.
Transparency	Chl-a and Turbidity	Default
Longitudinal dispersion	Fischer-numeric	Default
Phosphorus calibration	Decay rates (1)	Default
Nitrogen calibration	Decay rates (1)	Default

4.2.2 Model Inputs for Nine Mile Reservoir

4.2.2.1 Reservoir Morphometry

Model inputs were developed that describe average climatic and reservoir management conditions. The physical description of the reservoir's morphometry was calculated by correlating reservoir volume with average depth profiles throughout the reservoir and to area and length calculations. Reservoir elevation, overflow and volume data do not exist for the entire temporal range of water quality sampling activities nor are there specific elevation measurements taken on the same day water quality sampling occurred. However, reservoir elevation levels were correlated to reservoir volume using curve data provided by Rolan Beck (Gunnison Irrigation Company) and originally obtained by the engineer at the time of the dam's construction. Length of the reservoir was assumed to change by an equal percentage to area with changing depth.

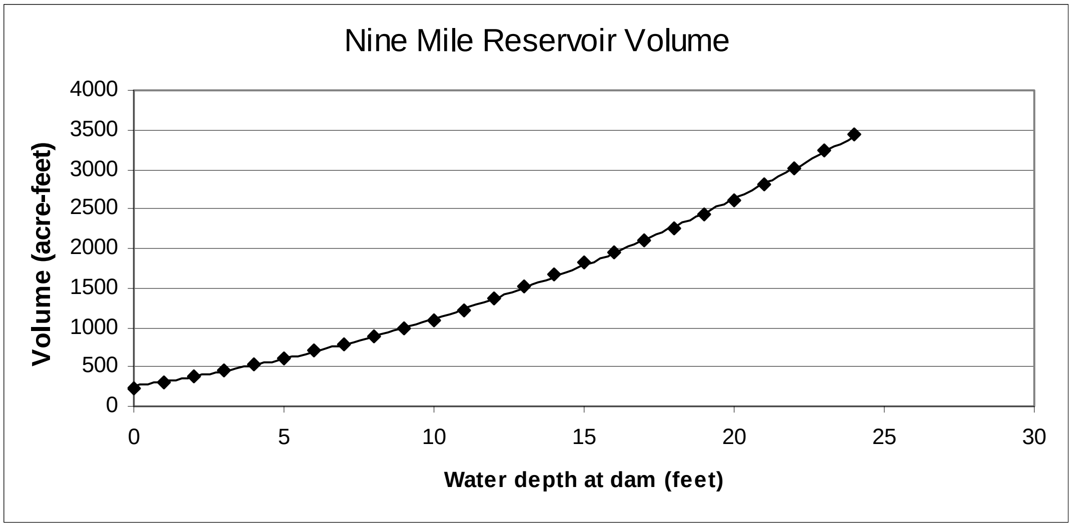


Figure 4.2 Correlation between reservoir volume and reservoir depth at dam.

Average reservoir volume during an average flow year was estimated to be 1,790 acre-feet with a corresponding area of 133 acres (0.54 km^2) and a mean depth of 4.08 meters. Mean reservoir volume was estimated using a monthly reservoir hydrograph developed based on the following assumptions.

- Spring discharge to the reservoir averages 200 acre-feet/month
- Average diversion from Six Mile Creek is 1000 acre-feet/year during the irrigation season
- Diversion from Six Mile Creek occurs, on average, at a rate ranging from 6 to 10 acre-feet/day between March and June, with higher diversion rates in warmer months.
- Reservoir drawdown begins on June 15 and goes until August 15 at an average rate of 50 acre-feet/day

Hypolimnetic depth was determined through examination of depth profiles of temperature and dissolved oxygen collected between 2000 and 2005 at various times of the year at various reservoir volumes. From these data the percent of the total depth that is represented by the hypolimnion and metalimnion was determined for the reservoir (Table 4.4).

Table 4.4 Calculation of Hypolimnetic Depth for Nine Mile Reservoir Average Conditions

Reservoir layer	Average percent water column	Average seasonal depth (m)*
Mixed layer	68%	2.76
Metalimnion	11%	0.45
Hypolimnion	21%	0.87
TOTAL	100%	4.08
*Assuming volume of 1,790 acre-feet		

4.2.2.2 Tributary Inputs

Nutrient concentrations for Six Mile Creek were determined using SWAT for the May–October period. The predicted mean total phosphorus concentration during this period is 0.013 mg/L including 0.05 mg/L of orthophosphate. The predicted mean total nitrogen concentration during the summer period was 1.43 mg/L with 0.9 mg/L of inorganic nitrogen. Flow diversion from Six Mile Creek was assumed to be 1,000 acre-feet per year during the irrigation season.

Loads from the Nine Mile Reservoir direct drainage watershed were also estimated using the SWAT model for the May – October period. The predicted total phosphorus concentration during this period is 0.029 mg/L including 0.011 mg/L of orthophosphate. The predicted mean total nitrogen concentration during the summer period was 1.44 mg/L with 1.0 mg/L of inorganic nitrogen. Runoff from the direct drainage area is estimated to be 0.061 cms (cubic meters per second).

Nutrient loads from the springs discharging to Nine Mile Reservoir were estimated using monitoring data for nutrient concentrations (0.011 mg/L total phosphorus; 0.15 mg/L total nitrogen) and an estimated flow of 200 acre-feet/month or 1.01 acre-feet/day. Based on these inputs, the total nutrient load to Nine Mile Reservoir for the May–October season was calculated and is summarized in Table 4.6.

Table 4.5 Summary of Phosphorus and Nitrogen Loads to Nine Mile Reservoir

	Phosphorus (kg/day)	Nitrogen (kg/day)
Six Mile Creek	0.08	5.89
Nine Mile direct drainage	0.39	1.72
Local springs	0.10	1.22
Precipitation	0.04	1.48
TOTAL	0.51	10.31

4.2.3 RESERVOIR MODEL RESULTS

4.2.3.1 Nutrients

Predicted average nutrient concentrations for Nine Mile Reservoir are 0.014 mg/L total phosphorus and 0.638 mg/L of total nitrogen. The majority of the nitrogen is predicted to be organic nitrogen (0.332 mg/L) and the majority of the phosphorus is predicted to be orthophosphate (0.011 mg/L).

The BATHTUB model also predicts total nitrogen to phosphorus ratios and dissolved nitrogen to phosphorus ratios. Values greater than 7 through 10 generally indicate a phosphorus limited system. The predicted N:P in Nine Mile Reservoir is 35, indicating a phosphorus limited system. This is supported by observed N:P discussed in Section 3.5.1.4.

4.2.3.2 Chlorophyll *a* and Secchi Depth

The predicted mean chlorophyll *a* concentration in Nine Mile Reservoir is 6 µg/L. Predicted percent exceedance of various chlorophyll *a* concentrations indicate the frequency at which nuisance algal levels are expected to occur in the reservoir under each condition. Exceedance of a nuisance threshold of 30 µg/L occurs less than 1% of the time. Exceedance of 10 µg/L, a value identified in the literature as protective of cold water fisheries and recreational uses is not predicted to occur under average reservoir conditions (Figure 4.3). Predicted Secchi depth in Nine Mile Reservoir is 2.9 meters.

4.2.3.3 Eutrophication Potential and Oxygen Depletion

The BATHTUB model outputs several metrics of eutrophication potential and oxygen depletion that can also be used to assess the suitability of the reservoir for cold-water fish. The initial results from a principal component analysis of reservoir response variables are expressed as an index value. Values greater than 500 are believed to indicate high eutrophication potential (Walker 1999). The value predicted for Nine Mile Reservoir is only 58. All of the predicted total phosphorus, chlorophyll *a*, and Secchi depth concentrations indicate a mesotrophic system.

The hypolimnetic oxygen depletion (HOD) rate predicts oxygen depletion below the thermocline and is related to the supply of organic matter from settling algae as well as to external organic sediment loads and hypolimnetic depth. When HOD is above 0.10 mg/L/day, the oxygen supply in the hypolimnion is usually depleted within 120 days (4 months) after stratification. Dissolved oxygen depth profiles collected at the Dam Site on June 15, 2005 and July 28, 2005 were compared and used to calculate actual oxygen depletion rates throughout the hypolimnion during the period of stratification. The calculation is based on guidance from the PROFILE and BATHTUB user manual (Walker 1999). Based on this analysis, HOD rates in Nine Mile Reservoir in summer 2005 were 0.07 mg/L/day. This calculation supports the finding that dissolved oxygen is greater than 4 mg/L throughout the majority of the water column throughout that stratification period (see Section 3.5.4.2).

4.2.3.4 Linkage to Water Quality Criteria

Based on examination of depth profiles, Nine Mile Reservoir appears to stratify for two months, in early June and mix again in early August. Initial hypolimnetic oxygen concentration at stratification is assumed to be 8.5 mg/L which is typical of reservoirs at stratification and is supported by the dissolved oxygen profiles observed in Nine Mile Reservoir. Assuming a hypolimnetic oxygen depletion rate of 0.07 mg/L/day, the hypolimnion of Nine Mile Reservoir would be reduced to only 4 mg/L in 120 days making the water quality criteria suitable for a cold water fishery. Since the reservoir is only stratified for 80 to 95 days, the model indicates that the reservoir is in full supporting status of the cold water fishery based on dissolved oxygen.

4.2.4 MODEL CALIBRATION AND VALIDATION

A reasonably robust dataset was available for validation of the Six Mile Creek portion of the SWAT model. The mean total phosphorus concentration observed in Six Mile Creek was 0.015 mg/L whereas the median total phosphorus concentration was 0.005 mg/L due to the overwhelming number of values that were recorded as Nondetects. The SWAT model predicts mean total phosphorus concentration in the creek at 0.012 mg/L which is between the mean and median values observed at this site.

Reservoir water quality data is not used directly in the BATHTUB model but is used to validate the model assumptions and tributary input data used to configure the reservoir model. Figure 4.3 shows that water quality predicted by the reservoir model is similar to average observed water quality in the reservoir.

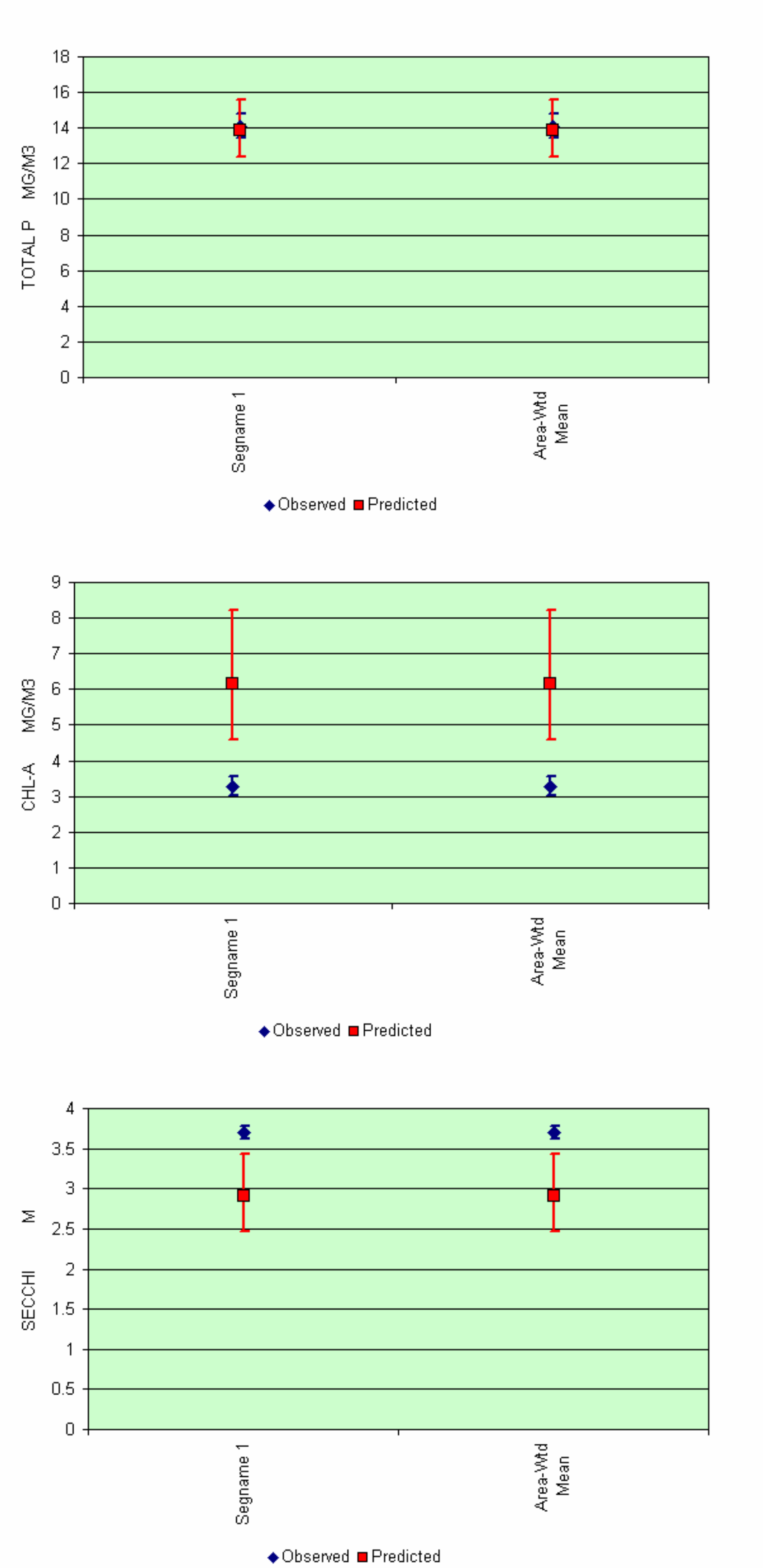


Figure 4.3 Model validation graphs for Nine Mile Reservoir BATHTUB model

4.3 MODEL UNCERTAINTY AND VARIABILITY

Watershed models are simplified abstractions of a natural system. No measurement within nature can be made without error, and the developed models cannot represent true spatial and temporal variability. Model outputs therefore present some level of uncertainty. Specific causes of uncertainty include lack of appropriate data pertaining to watershed output, conflicting data, data ambiguity, and measurement uncertainty. Uncertainty in estimating nutrient loads produced within the watershed comes primarily from the following.

1. Errors in weather station data
2. Errors related to weather station location
3. Errors in nutrient parameter adjustments
4. Errors associated with the SWAT or BATHTUB models themselves
5. Errors that result from combining the SWAT and BATHTUB models

Since the SWAT model is a spatially distributed and physically based model, output modification is accomplished by parameter adjustment. Because of the lack of physical data available for the watershed, computer parameter sensitivity methods are not available and manual parameter modification and measurement become very tedious and time consuming, with limited complexity. Uncertainty in model output is increased with the use of arbitrary parameter-estimation methods. However, recent studies have demonstrated that a direct comparison of model output for a complete dataset versus an incomplete dataset did not produce large discrepancies in model performance (Wainwright 2004). Since SWAT produced results meeting acceptable calibration measurement performance, the SWAT model outputs were determined to be appropriate for use in this watershed analysis.

4.4 CONCLUSIONS

The combination of SWAT watershed modeling and the BATHTUB reservoir model provides additional evidence for recommending that Nine Mile Reservoir be removed from the State of Utah's 303(d) list for impaired waters. The model suite is quite conservative, slightly over-predicting nutrient loads, concentrations, and trophic condition in all cases. Despite this over-prediction, the model suggests that on average, Nine Mile Reservoir remains below the total phosphorus threshold of 0.025 mg/L during the summer algal growth season and the chlorophyll *a* concentrations remain below 10 µg/L during this same period. Oxygen depletion estimates indicate that the reservoir will not deplete more than 50% of the water column is maintained at a dissolved oxygen concentration above 4 mg/L when the reservoir is maintained at its average volume of 1,790 acre-feet.

5 SUMMARY OF EVIDENCE FOR DELISTING

5.1 WATER QUALITY SUMMARY

5.1.1 COMPLIANCE WITH WATER QUALITY CRITERIA

There have been no observed exceedances of the dissolved oxygen criteria established by the State of Utah in Nine Mile Reservoir since 1999. More than 50% of the water column meets dissolved oxygen criteria of greater than 4.0 mg/L during all months at both sites; therefore the reservoir is in full support status for the cold water fishery designated beneficial use based on dissolved oxygen criteria. This conclusion is supported by an analysis of nutrient and chlorophyll *a* data available for Nine Mile Reservoir.

Current mean and median total phosphorus concentrations are below the indicator threshold established by the State of Utah. This threshold of 0.025 mg/L is rarely exceeded in Nine Mile Reservoir, with more than half of the data points available for the reservoir recorded as nondetect, and therefore below the detection limit of 0.01 to 0.02 mg/L (depending on the analytical method used). Exceedances appear to be associated primarily with low reservoir water levels, during which time phosphorus in-bed sediment is more likely to be suspended throughout the water column. Since no conservation pool has been established for this reservoir, management of the reservoir level is not negotiable. Chlorophyll *a* values are also well below the indicator values of 10 µg/L identified in the literature as being protective of cold water fisheries and recreational uses.

5.1.2 TREND TOWARDS IMPROVING WATER QUALITY

Trend data for total phosphorus concentration, chlorophyll *a*, and Secchi depth indicate that water quality in the reservoir has been improving since 2000, with the exception of one high total phosphorus concentration identified in the summer 2006.

5.1.3 COMPARISON WITH PALISADES LAKE

A comparison between Nine Mile Reservoir and Palisades Lake, both of which receive inflow from Six Mile Creek, indicates that pH and alkalinity are significantly higher in Nine Mile Reservoir than in Palisades Lake. This provides another line of evidence that high pH in Nine Mile results from the alkaline soils in the surrounding area. Mean total phosphorus and dissolved oxygen, based on a detailed water column analysis, is similar between the two systems, indicating that Nine Mile Reservoir should not be listed as impaired for this water quality parameter. Water column dissolved oxygen values are comparable between the two reservoirs at specific depths and often lower in Palisades Lake. The lowest dissolved oxygen measurement in Nine Mile Reservoir is at a depth lower than the maximum depth for Palisades Lake, making it difficult to compare the two systems at such depths. It is expected that a larger hypolimnion forms in the deeper Nine Mile Reservoir and that stratification takes place for a longer period of time, resulting in lower dissolved oxygen at the sediment-water interface.

5.2 Explanation of Observed Water Quality Exceedances

5.2.1 Naturally Alkaline Soils

Elevated pH levels in Nine Mile Reservoir are associated with naturally alkaline soils in the watershed and that extend below the reservoir. This natural condition results in the exceedance of the pH criteria established for cold water fisheries by the State of Utah.

5.2.2 Correlation Between Water Quality and Reservoir Level

There have been no observed exceedances of dissolved oxygen criteria in Nine Mile Reservoir since 1999. The few incidences of elevated chlorophyll *a* and total phosphorus correlate well with low reservoir water levels. Since no conservation pool has been established for Nine Mile Reservoir, when the reservoir is drawn down to its minimum level it no longer can support fish due to a lack of water. When the reservoir maintains only a relatively small pool of water it can quickly become stagnant and warm, thereby reducing viable habitat for a cold water fishery and promoting in-reservoir algal growth. Watershed level nutrient reductions would not have a substantial improvement on this condition, which is primarily a function of reservoir level management and water rights.

5.2.3 Drought Associated Temperature Exceedance

Nine Mile Reservoir has little natural cover and the watershed is located in an area experiencing warm, dry climate conditions. The State of Utah recently conducted an assessment of temperature inputs to several local water bodies and determined that the primary source of temperature loading was from solar radiation and heat transfer. Exceedances of the cold water temperature criteria occurring in the Six Mile Creek diversion inflow data, and spring inflow data indicate that both inflow and in-reservoir heating processes are responsible to some degree for the elevated water temperatures observed. Nine Mile Reservoir was not determined to be impaired for temperature on the 2006 303(d) list.

5.3 Other Indicators of Trophic State

Analysis of the trophic state index (TSI), fishery, and phytoplankton composition for Nine Mile Reservoir add further support to a full support designation for Nine Mile Reservoir. The reservoir is generally mesotrophic. Occurrences of reduced turbidity measured in terms of Secchi depth generally indicate a non-algal source of light interference associated with the high-alkaline water in the reservoir. There have been no documented fish kills in the reservoir and blue-green algae species are not prevalent.

5.4 Modeled Water Quality

The combination of SWAT watershed modeling and BATHTUB reservoir model provides additional evidence for recommending that Nine Mile Reservoir be removed from the State of Utah's 303(d) list for impaired waters. The model suite is quite conservative, slightly over-predicting nutrient loads, concentrations, and trophic condition in all cases. Despite this over-prediction, the model suggests that on average Nine Mile Reservoir remains well below the total phosphorus threshold of 0.025 mg/L during the summer algal growth season and that chlorophyll *a* concentrations remain below 10 µg/L during this same period. Oxygen depletion estimates indicate that the reservoir will maintain dissolved oxygen concentrations above 4 mg/L in more than 50% of the water column when the reservoir is maintained at its average volume of 1,790 acre-feet.

Bibliography

AITC (Agriculture in the Classroom). 2005. *Agricultural hard times and the Great Depression 1920–1930, Screens 5 and 6*. Utah State University Extension. http://extension.usu.edu/aitc/

American Public Health Association (APHA). 1992. *Standard methods for the Examination of Water and Wastewater*, 18th edition. American Public Health Association, Washington DC.

Carlson, R.E. 1992. *Expanding the trophic state concept to identify non-nutrient limited lakes and reservoirs*. pp. 59-71 [In] Proceedings of a National Conference on Enhancing the States' Lake Management Programs. Monitoring and Lake Impact Assessment. Chicago.

Carlson, R.E. 1977. A Trophic State Index for Lakes. Limnology and Oceanography 22 (2):361-369.

City Data. 2006. *Sterling, Utah.* Available at: http://www.city-data.com/city/Sterling-Utah.html

EPA. 1983. *Methods for Chemical Analysis of Water and Wastes (1983)*, USEPA, EPA 600/4-79-020.

Environmental Protection Agency (EPA). 2000b. EPA 822-B00-001. *Nutrient Criteria Technical Guidance Manual: Lakes and Reservoirs*. United States Environmental Protection Agency Office of Water, Washington DC. July 2000. URL: www.epa.gov/ost/standards/nutrient.html.

Hedley, M.J., Mortvedt, J.J., Bolan, N.S., Syers, J.K. 1995. *Phosphorus Fertility Management in Agrosystems*. Chapter 5 in Phosphorus in the Global Environment: Transfers, Cycles and Management; Tiessen, H.; (ed.); John Wiley and Sons, Chichester.

Lowe, M., Wallace, J., Bishop, C.E. 2002. *Water-quality assessment and mapping for the principal valley-fill aquifer in Sanpete Valley, Sanpete County, Utah*. Utah Geological Survey, Special Study 102. 91 p.

National Climatic Data Center. (NCDC). 2004. *Daily Climate Data* [internet website]. National Climatic Data Center, National Oceanic and Atmospheric Administration. Available at http://www.ncdc.noaa.gov/paleo/pdsi.html

Neitsch, S.L., Arnold, J.G., Kiniry, J.R., Williams, J.R., King, K.W. 2002. *Soil and Water Assessment Tool, Theoretical Documentation*. Grassland, Soil, and Water Research Laboratory, Agricultural Research Service. Temple, Texas.

Omernik, J.M.; Gallant, A.L. 1986. *Ecoregions of the Northwest*. EPA/600/3-86/033; 39 pP.

Pilgrim, K., D. Sanders, and T. Dupuis. 2001. *Relationship between chlorophyll a and beneficial uses*. CH2M Hill, Boise, Idaho. 10 p.

Rashke, R. L. 1994. Phytoplankton bloom frequencies in a population of small southeastern impoundments. *Lake and Reservoir Management* 8(2): 205-210.

Robinson, G.B. 1971. *Ground water Hydrology of the San Pitch River drainage basin, Sanpete County, Utah.* US Geological Survey, Water Supply Paper #1896. 80 p.

Rocky Mountain Research Station (RMRS). 2005. Prevedel, David A.; McArthur, E. Durant; Johnson, Curtis M. *Beginnings of Range Management: An Anthology of the Sampson-Ellison Photo Plots (1913 to 2003) and a Short History of the Great Basin Experiment Station*. General Technical Report: RMRS-GTR-154. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 60 p.

Rushforth, S. R., and S. J. Rushforth. 2001. *A study of phytoplankton floras from Utah lakes and reservoirs collected late summer 2000.* Report to the Utah Division of Water Quality.

Rushforth, S. R., and S. J. Rushforth. 2003. *A study of phytoplankton floras from Utah lakes and reservoirs collected late summer 2002.* Report to the Utah Division of Water Quality.

Rushforth, S. R., and S. J. Rushforth. 2005. *A study of phytoplankton floras from Utah lakes and reservoirs collected late summer 2004.* Report to the Utah Division of Water Quality.

Sabater, S. and W. Admiraal. 2005. *Periphyton as biological indicators in managed aquatic ecosystems*. pp. 159-177 In: Azim, M. E., Verdegem, M. C. J., A. A. van Dam, and M. C. M. Beveridge (eds.). Periphyton: Ecology, Exploitation and Management. CABI Publishing, Cambridge, Massachusetts. 319 p.

Sharpley, A.N., Hedley, M.J., Sibbesen, E., Hillbricht-Ilkowska, A., House, W.A., Ryszkowski, L. 1995. *Phosphorus transfers from terrestrial to aquatic ecosystems*. Chapter 11 In Phosphorus in the Global Environment: transfers, cycles and management; Tiessen, H.(ed.); John Wiley and Sons, Chichester.

Sharpley, A.N.; Jones, C.A.; Grey, C.; Cole, C.V. 1984. A simplified soil and plant phosphorus model II: Prediction of labile, organic and sorbed phosphorus; *Soil Science Society of America Journal* 48: 805-809.

Snyder, N.P., Lowe, M. 1998. *Map of Recharge Areas for the Principal Valley-Fill Aquifer, Sanpete Valley, Sanpete County, Utah.* Utah Department of Natural Resources, Utah Geological Survey. In cooperation with Utah Department of Environmental Quality, Division of Water Quality. ISBN 1-55791-619-5.

Spieker, E.M. 1946. *Late Mesozoic and early Cenozoic history of central Utah, IN Shorter contributions to general geology, 1943-45*. U.S. Geological Survey Professional Paper, 205-D, p. D117-D161.

Stokes, W.L. 1986. *Geology of Utah.* Utah Geological and Mineral Survey Department of Natural Resources.

Tiessen, H. (ed.). 1995. *Phosphorus in the Global Environment: Transfers, Cycles and Management*. Scientific Committee on Problems of the Environment (SCOPE) 54; John Wiley and Sons, Chichester.

U.S. Census Bureau: State and County. 2007. *QuickFacts: Data derived from Population Estimates, Census of Population and Housing, Small Area Income and Poverty Estimates, State and County Housing Unit Estimates, County Business Patterns, Nonemployer Statistics, Economic Census, Survey of Business Owners, Building Permits*. Consolidated Federal Funds Report

USDA (United States Department of Agriculture). 1981. *Soil Survey of Sanpete Valley, Utah: Parts of Utah and Sanpete Counties.* United States Department of Agriculture, Soil Conservation Service, and United States Department of the Interior, Bureau of Land Management. In cooperation with the Utah Agricultural Experiment Station and Utah State Department of Natural Resources. September 1981.

USFS (United States Forest Service). 2006. *Manti La-Sal National Forest GIS data*. Price, UT. [May 23, 2006]. Available at http://www.fs.fed.us/r4/mantilasal/publications/downloads/index.htm

Utah Division of Water Rights. 2006a. *Dam safety database.* Salt Lake City, UT. [May 23, 2006]. Available at http://www.waterrights.utah.gov/cgi-bin/damview.exe?Startup

Utah Division of Water Rights. 2006b. *WRPLAT Point of Diversion Query Program.* http://utstnrwrt6.waterrights.utah.gov/cgi-bin/wrplat.exe?Startup [viewed October 20, 2006]

Utah Division of Water Quality (UDWQ), Department of Environmental Quality. 2007. Lake report: Nine Mile Reservoir. URL: http://www.waterquality.utah.gov/watersheds/lakes/NINEMILE.pdf. [viewed 3/14/2007].

Utah Division of Wildlife Resources. 2006. *Utah Natural Heritage Program database*. written communication with Sarah Lindsey October 16, 2006.

Utah History Online. 2006. Information citing Gary B. Peterson, and Miriam B. Murphy (History Blazer July 1996). Available at: http://www.onlineutah.com/sanpetecountyhistory.shtml

Utah Division of Water Quality (DWQ), Department of Environmental Quality. 2003. *San Pitch River Watershed: Water Quality Management Plan.*

Wainwright, J., Mulligan, M. 2004. *Environmental Modeling: Finding Simplicity in Complexity*. John Wiley and Sons, Ltd. London, UK., Part 1, pages 56-58.

Weiss, M.P. 1994. *Geology of the Sterling quadrangle, Sanpete County, Utah*. Utah Geological Survey Open-File Report 159, 26 p., scale 1:24,000.

Welsh, S. L., N. D. Atwood, L. C. Higgins, and S. Goodrich. 2003. *A Utah Flora*. Third ed. Provo, Utah: Brigham Young University.

Western Regional Climate Center (WRCC). 2006. *Western Regional Climate Center.* Available at: www.wrcc.sage.dri.edu/summary/climsmut.html

Wetzel, R.G. 2001. *Limnology: Lake and River Ecosystems.* 3rd Edition ed. San Diego: Academic Press.