MANNING MEADOWS RESERVOIR

LIMNOLOGICAL ASSESSMENT OF WATER QUALITY

March 2008

Manning Meadows Reservoir Report
March 6, 2008

Manning Meadows Reservoir is listed by the State of Utah as an impaired water body because dissolved oxygen and total phosphorus does not meet State water quality standards. In partnership with Utah Division of Water Quality (UDWQ), personnel of the Fishlake National Forest (WCNF) collected data from Manning Meadows Reservoir from March 2006 to October 2006 to provide recent detailed water quality information to support a Total Maximum Daily Load (TMDL) analysis. This report contains information listed below.

- Sections 1.0 and 2.0: Description of the water body and associated watershed, the nature of the impairment; water quality standards of the parameters of concern for the water body.
- Section 3.0: Discussion of whether the impairments are naturally occurring and, if not, what water body targets and endpoints should be recommended.
- Section 4.0: Discussion of which land management activities are contributing to the impairment, what practices may be recommended to reduce sources of impairment, and an estimate of the acceptable load or the degree to which the current pollutants (loads) need to be decreased to attain the defined endpoints.
- Section 5.0: Identification of significant pollutant sources through use of existing information (maps, reports, inventories, and analyses) and new data.
- Section 6.0: Description of water quality data in relationship to abiotic and biological processes.
- Section 7.0: All sources contributing to impairment will be evaluated and a determination of beneficial use support will be presented.
- Section 8.0: The rationale for addressing all sources and causes that are significant for the attainment of water quality targets.

Figure 1. Manning Meadows Reservoir

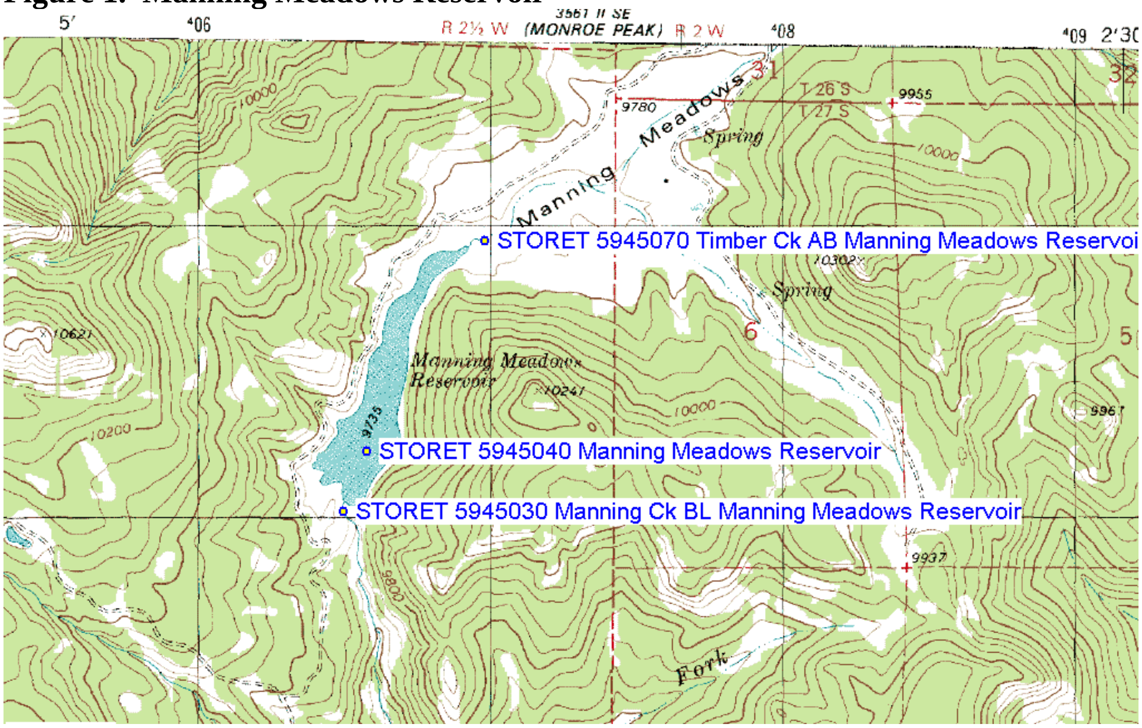
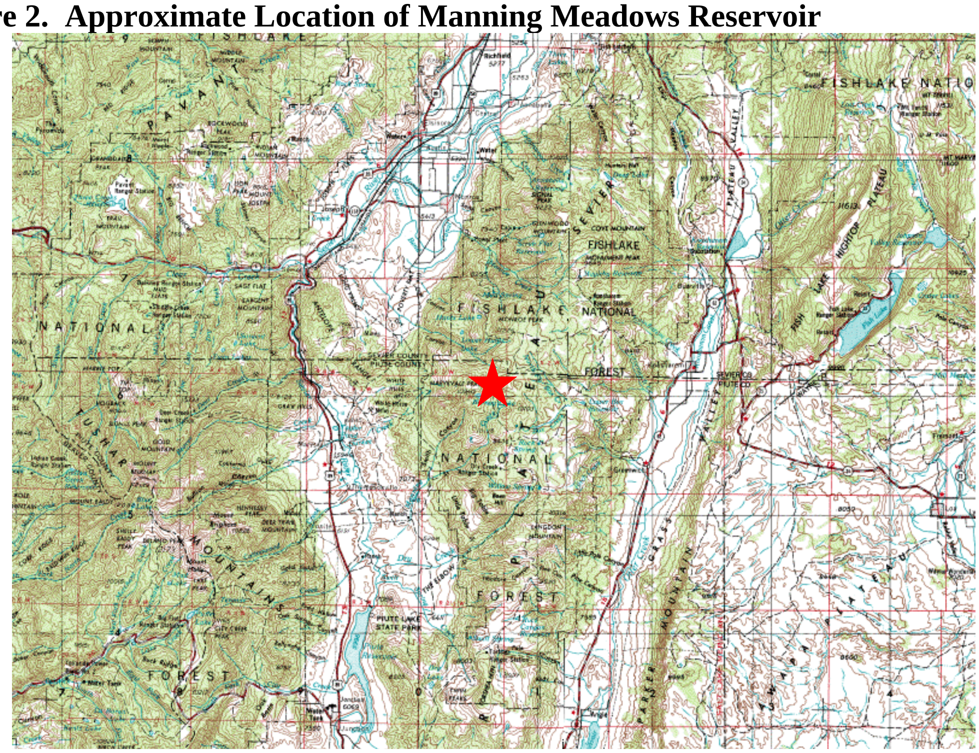


Figure 2. Approximate Location of Manning Meadows Reservoir



1.0 Introduction

Manning Meadow Reservoir is an impoundment of a high mountain meadow by an earthen dam. The reservoir has a surface area of 59 acres, volume of 996 acre-feet, and a mean depth of 5.5 meters. It is located at an elevation of 9,750 feet above mean sea level on the Fishlake National Forest in Piute County on the Sevier Plateau. The watershed area is 1,186 acres (Judd 1997).

Surface inflows to the reservoir consist primarily of Manning Creek and Timber Creek. Manning Creek is located in a meadow that extends upstream from the reservoir in a small valley, filled with sedges and grasses. Manning Creek above the reservoir is a large bog where water spreads and flows slowly. Water quality samples were collected from a 0.3 feet (4") deep pool where it was clear, although the bottom of the pool was covered with silt. The bog area is 400' wide and the area where water is the deepest, up to 0.3 feet deep, is 25 feet wide. The creek is not aggrading or degrading. The average gradient of the meadow above the reservoir is 1.9 percent (Judd 1997). When water quality samples were taken, water in Timber Creek was about one foot wide and 0.1 feet deep. The Timber Creek water quality sample site is located above the dirt road and above the Utah Division of Wildlife Resources trout egg collect station that is on Timber Creek.

The watershed above the reservoir is 1,186 acres in size. The watershed receives 25 to 30 inches of precipitation annually with a frost-free season of 20-40 days. Most of the precipitation occurs in the form of snow that falls during the winter. The soil is of volcanic origin and has moderate permeability and moderately slow erosion and runoff. Phosphorus occurs naturally from the volcanic geology of the watershed and the volcanic soils can have high concentrations of inorganic phosphorus. The immediate area around the reservoir is sagebrush-grass with aspen and conifer forest growing on the slopes surrounding the valley bottom. The reservoir is in an area of high, rolling ridges and valleys characteristic of the Sevier Plateau (Judd 1997).

Several land uses occur within the watershed draining into the reservoir. The only recreational facility at the reservoir is one toilet, and the area offers itself to primitive camping. There are no Forest Service campgrounds in the area. A Utah Division of Wildlife Resources trout egg collect station is located on Timber Creek between the reservoir and the dirt road next to the reservoir. At the egg collection station, there is a bare parking pad for two vehicles and the egg collection site in the stream is made of concrete. People launch their boats into the reservoir from a two-track path leading to the reservoir edge near the dam. Some dispersed recreation sites are located west of the dam near this area. The shoreline around the reservoir is owned and managed by the Forest Service with unlimited public access. Private land makes up 312 acres or 29% of the drainage area, and Forest Service land makes up 774 acres or 71% of the drainage area. Other land uses include private summer home recreation, cattle and sheep livestock grazing, snowmobiling, backpacking, camping, and hunting and fishing. Usage is light except during the hunting season.

Most of the ground cover in the watershed above the reservoir is in good condition. An 88 acre slope above the reservoir was burned several years ago but the area has recovered and no accelerated erosion is occurring at the present time. The dirt road that is on the west side of the reservoir has proper drainage structures and is maintained by the county. On private land near the summer homes, some ruts in the road tend to pool water. The shore surrounding the reservoir has dense vegetation in most areas.

2.0. Water Quality Standards

This section discusses the associated impairment and parameters of concern with respect to state water quality standards, antidegradation policies and designated beneficial uses for Manning Meadow Reservoir.

The State of Utah has designated the waters within the reservoir as Antidegradation Segments indicating that the existing water quality is better than the established standards for the designated beneficial uses. Water quality is required by state regulation to be maintained at this level. The beneficial uses of streams within the Forest, as designated by the Utah Department of Environmental Quality, Division of Water Quality, are Class 2B – protected for recreation; Class 3A – protected for cold water species of game fish and other cold water aquatic species; and Class 4 – protected for agricultural uses (Utah, State of 2005).

Manning Meadow Reservoir is listed as impaired for dissolved oxygen and total phosphorus for Cold Water Species of Game Fish (Beneficial Use Class 3A). The methodology for listing these parameters are described below.

Listing methodology for Dissolved Oxygen

The listing methodology employed by Utah to assess Class 3A (aquatic life) beneficial use for dissolved oxygen (DO) involves evaluating the reservoir profile data collected at the surface and at one meter intervals to determine the percentage of the water column that falls below the one day average value of 4.0 milligrams per liter (mg/L). For stratified lakes, the beneficial use is supported if the dissolved oxygen concentrations are greater than the dissolved oxygen standard in at least 50% of the water column depth. For non-stratified lakes, the beneficial use is supported if at least 90% of the oxygen measurements are greater than the dissolved oxygen standard for the entire water column depth. (Utah, State of 2007).

Table 1. Utah's Dissolved Oxygen Criteria for Class 3A waters (R317-2; Standards of Quality for Waters of the State).		
Timeframe	**Minimum Dissolved Oxygen**	**Explanations**
30 day average	6.5 mg/l	
7 day average	9.5/5.0 mg/l	Not to exceed 110% of saturation. 9.5 when early life stages are present. 5.0 when all other life stages present
1 day average	8.0/4.0 mg/l	Not to exceed 110% of saturation. 8.0 when early life stages are present. 4.0 when all other life stages present

In addition, an evaluation of the trophic state index (TSI), winter dissolved oxygen conditions with reported fish kills, and the presence of significant blue green algal species in the phytoplankton community is made. If two of these three additional criteria indicate a problem, the support status can be shifted downward.

Lastly, the historical beneficial use support is evaluated for the water body in question. If a waterbody shows that beneficial use impairment consistently exists, the waterbody should be listed on the 303(d) list. However, if a waterbody exhibits a mixture of partially and fully supporting conditions over a period of years, the waterbody should continue to be evaluated.

Listing Methodology for Total Phosphorus

Total phosphorus does not directly affect aquatic life, but as a nutrient it can stimulate growth of aquatic algae and emergent plants. Nuisance blooms of algae and other aquatic plants can have a negative effect on the amount of dissolved oxygen and habitat for fish and their food supply (macroinvertebrates). The assessment methodology employed by Utah for total phosphorus is; a waterbody needs further study if more than 10% of the phosphorus measurements at the surface, above the thermocline, below the thermocline and at the bottom exceed 0.025 mg/l. If further study is needed, other factors such as fish kills, low dissolved oxygen, blue-green algae dominance, and the Trophic State Index (TSI) are considered in the evaluation.

An assessment of the water quality conditions in Manning Meadow Reservoir in 1997 (Judd 1997) is described below.

> The water quality of Manning Meadow Reservoir is good. It is considered to be soft with a hardness concentration value of approximately 31 mg/L (CaCO3). The only parameters that have exceeded State water quality standards for defined beneficial uses are phosphorus and dissolved oxygen. The average concentration of total phosphorus in the water column in 1992 was 113 ug/L which exceeds the recommended pollution indicator for phosphorus of 25 ug/L. Phosphorus concentration in the hypolimnion have been as high as 396 ug/L and during August 5, 1992 averaged 163 ug/L. These high concentrations of nutrients lead to the production of algal blooms. Such a high amount of production can lead to anoxic problems in the water column. As depicted in the August 5, 1992 profile these types of conditions manifest themselves. The reservoir is stratified at the 4 meter depth and below that the dissolved oxygen concentrations decline rapidly to a low of 0.5 ug/L near the bottom of the reservoir. Dissolved oxygen concentrations in late summer and winter substantiate the fact that water quality impairments do exist. These conditions are deleterious to the fishery, rendering large portions of the

water column unsuitable for a fishery. In addition dissolved oxygen concentrations may reach critical state during the winter period for fish.

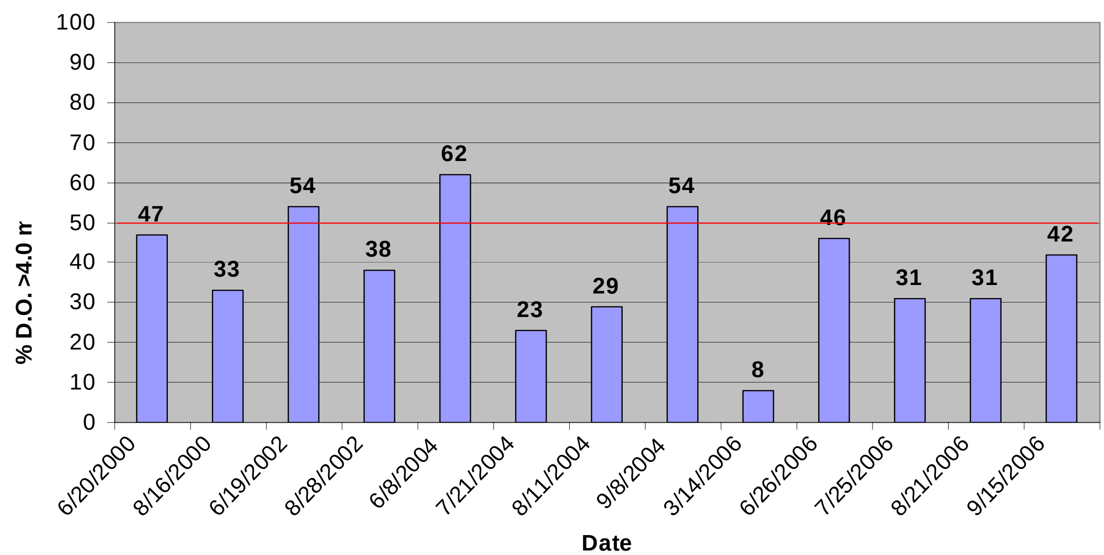
Current data suggest that the reservoir is a nitrogen limited system. TSI values indicate that the reservoir is highly productive and classified as a eutrophic system. According to DWR no fish kills have been reported in recent years. The reservoir supports populations of splake, a cross of brook trout (*Salvelinus fontinalis*) with lake trout (*Salvelinus namaycush*), and Bonneville cutthroat trout (*Oncorhynchus clarki utah*). DWR maintains a breeding population of these cutthroat trout in the reservoir. The lake was treated for rough fish competition in 1989 so that management of the fishery for these fish could occur. According to recent stocking records, advanced fingerling Bonneville cutthroat trout and Splake (male brook trout X female lake trout) (*Salvelinus fontinalis* male X *Salvelinus namaycush* female) continue to be stocked in the reservoir. The flora is fairly typical, but not particularly diverse. The dominance of blue- green algae and diatoms indicates that the lake has fairly good water quality with eutrophic conditions present in the reservoir.

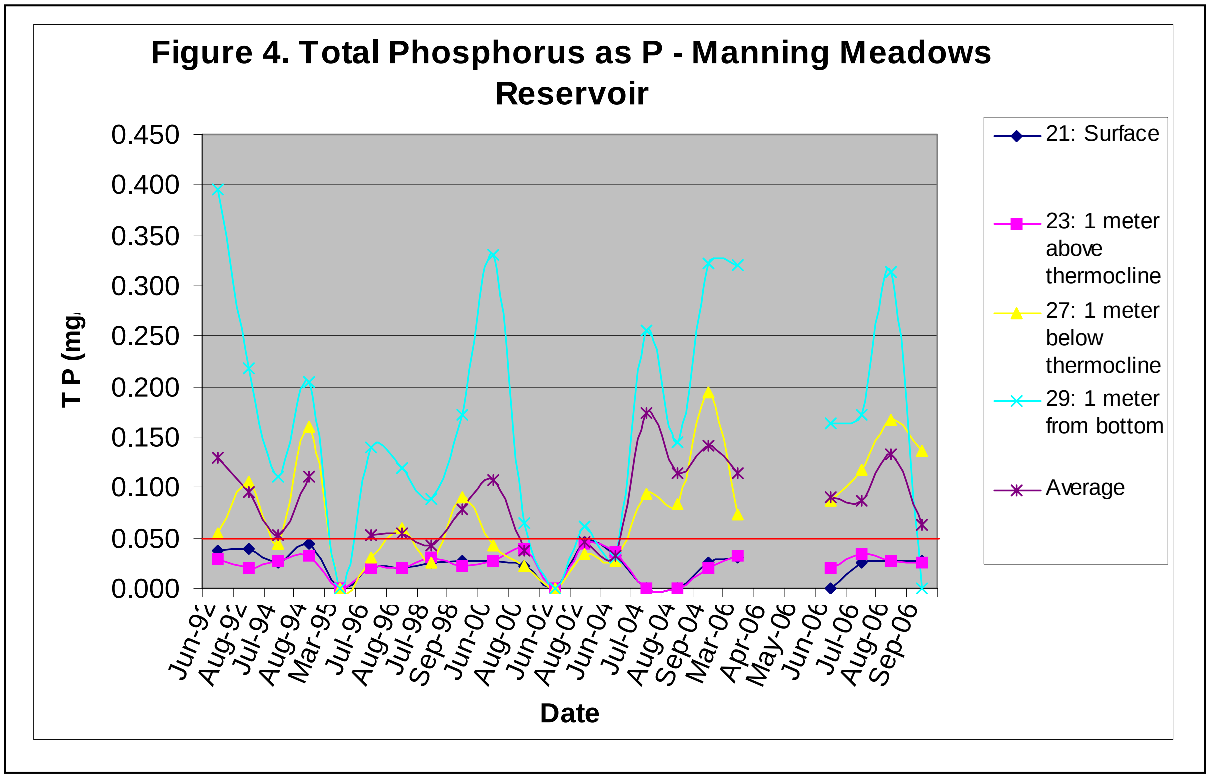
Pollution Assessment

The nonpoint sources of pollution in Manning Meadows Reservoir is sedimentation and nutrient loading from grazing, and travel routes in the watershed and in the vicinity of the reservoir. Grazing activity is extensive and is contributing to the nutrient load as indicated by the reservoir response in recent years. The grazing allotment is in the Manning Creek Allotment. There are no point pollution sources in the watershed.

Water quality data collected since 1997 indicate that the assessment described above is an accurate description of water quality conditions in Manning Meadow Reservoir. As seen in Figure 3, 3 of 13 (23%) profiles fully meet State standards of 50% of the profile supporting 4 mg/l DO. In 2006, none of the profiles met this standard. As shown in Figure 4, most of the total phosphorus as P values exceeds the State indicator value. The total phosphorus exceedances (greater than 0.025 mg/l) from 1992 through 2005 are 47 of 60 samples (78.3%) and in 2006 are 17 of 19 samples (89.5%).

Figure 3. Manning Meadows Reservoir -
Percent of Water Column Supporting 4 mg/l D.O. Criteria





This section discusses which land management activities are contributing to the impairment, practices recommended to reduce sources of impairment, and an estimate of the acceptable load or the degree to which the current pollutants (loads) need to be decreased to attain the defined endpoints.

Most of the total phosphorus in the Timber Creek drainage is in the dissolved fraction indicating natural spring sources for total phosphorus and not soil disturbance. Recommended practices to reduce sources of phosphorus loading from Manning Creek are:

- On private land, consolidate specific ATV and truck routes in the watershed draining into Manning Creek and tributaries in order to reduce the numerous trails and routes, some of which cross Manning Creek and the southern tributary of Manning Creek. Avoid wet areas and avoid crossing Manning Creek or use small bridges to cross. Move cattle frequently to keep livestock from congregating and denuding vegetation in the upland and spring areas.
- On National Forest lands, maintain the fence that keeps livestock out of the wetland area of Manning Creek just above the reservoir. Designate areas where dispersed camping should occur and control soil erosion from these areas. Limit vehicle access to the reservoir to one boat launch and create proper drainage for this route to control erosion and sediment transport. Where soil erosion appears to be causing sediment to enter the reservoir, use best management practices to control erosion such as planting grasses and mulching bare soil areas, and placing barriers such as branches and rocks in unwanted paths.

It is anticipated that these practices will reduce the anthropogenic load of total phosphorus in the reservoir but additional monitoring will be required to determine if and when water quality endpoints are met.

5.0 Significant Sources

The primary anthropogenic sources of phosphorus entering the reservoir are from a few areas on private land and National Forest land which are listed below.

- On private land, numerous trails and routes caused by trucks and ATVs, some of which cross Manning Creek and the southern tributary of Manning Creek. Few bare spots in the upland and in spring areas caused by trampling and over-grazing by livestock and wildlife.
- On National Forest land, bare soil along two-track path leading to the reservoir that is used as a boat launch and dispersed camping sites near dam.

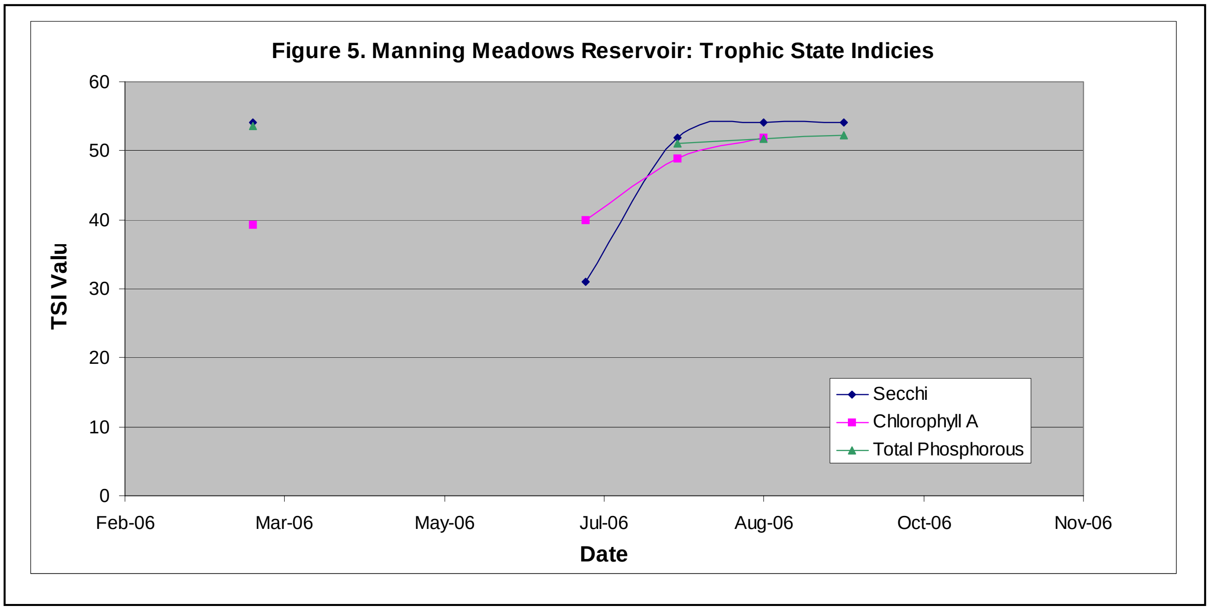
6.0 Technical Analysis

This section contains a description of water quality data conditions at Manning Meadow Reservoir, a discussion containing a summary by Bronmark and Hansson (2005) of abiotic and biological processes that occur in lakes and ponds, and a comparison of these concepts with the water quality conditions of Manning Meadow Reservoir.

Trophic State – Carlson's Trophic State Index (TSI) is used to determine the biological productivity of a lake using three indicators, chlorophyll a (indicative of the amount of algae), secchi depth (indicative of water clarity) and total phosphorus (a critical nutrient for algae growth). The TSI for a lake is determined using regression equations and values for chlorophyll a, secchi depth, and total phosphorus. Carlson states that the best parameter to use for the index is chlorophyll a and transparency should be used only if no other parameter is available (Kent State 2005).

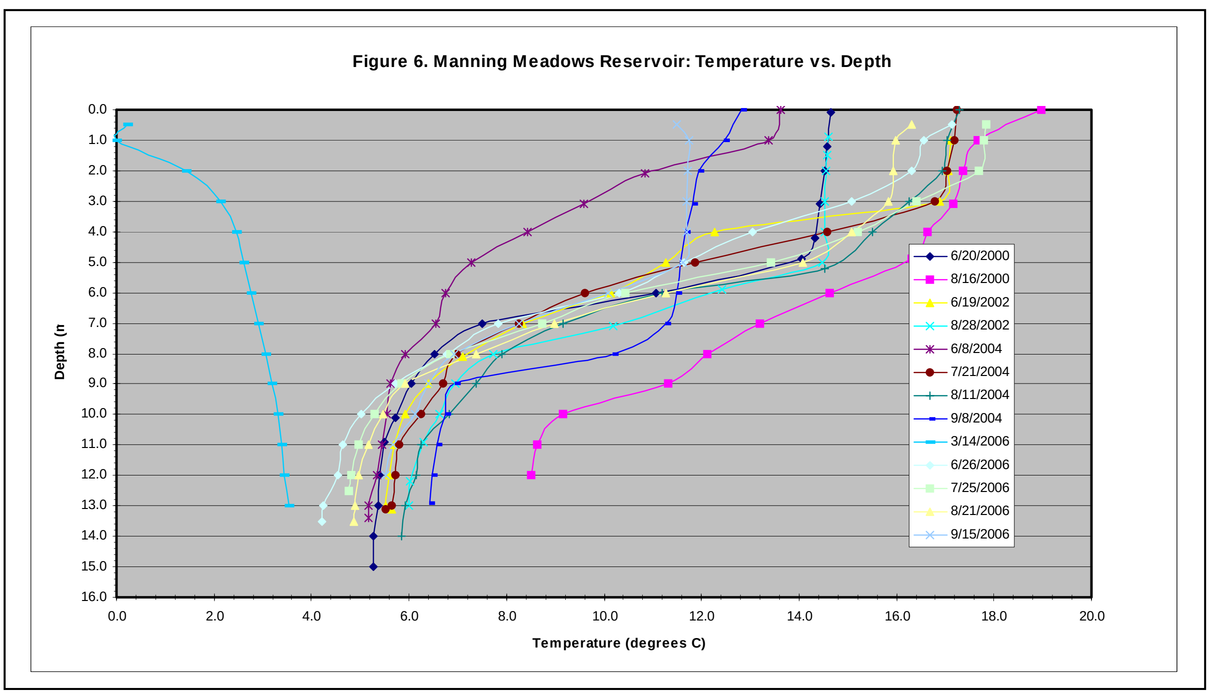
Carlson's TSI values classify northern temperate lakes into three general categories, oligotrophy, mesotrophy and eutrophy. Oligotrophic lakes are characterized by clear water and oxygen throughout the year in the hypolimnion (bottom water layer in a lake. Mesotrophic lakes are characterized by moderately clear water and an increasing probability of hypolimnetic anoxia (low DO) during summer. Eutrophic lakes are characterized by anoxic hypolimnia and macrophyte problems (Kent State 2005).

Based on water sampling of Manning Meadow Reservoir in 2006 and 2007, the trophic state index of chlorophyll-a during the winter and early summer is mainly mesotrophic. The trophic state index for secchi depth reflects a similar pattern but indicates a more eutrophic state and gave values that were between upper oligotrophic and eutrophic. Trophic state based on total phosphorus was consistently eutrophic.



Lake Morphology – Manning Meadow Reservoir is somewhat tear-drop in shape and is about 800 feet wide, 5,000 feet long, and has a mean depth of 18.1 feet (5.5 meters).

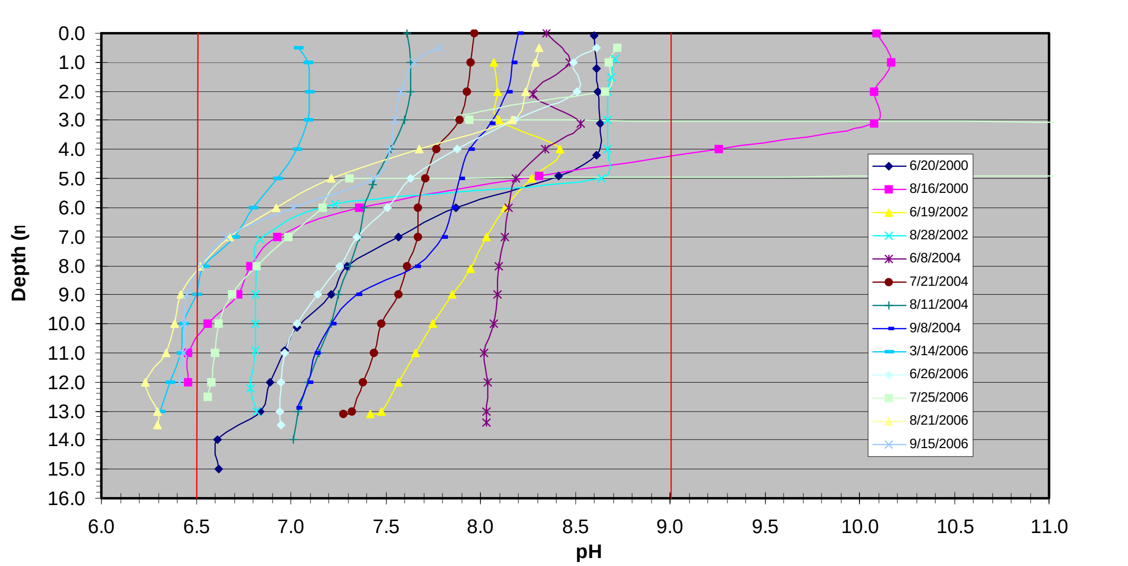
Temperature – The temperature of Manning Meadow Reservoir ranges in winter from 0ºC at the surface to 3.5ºC at the bottom and in summer from 11.5 to 19.0ºC at the surface and from 4.2 to 8.5ºC near the bottom at a depth of 13.0 to 14.0 meters. The temperature profile indicates that the reservoir is stratified during the summer season with a thermocline occurring between 3 to 7 meters.



Light (secchi depth) – The secchi depth in Manning Meadow Reservoir in 2006 and 2007 ranged from 1.0 to 7.5 meters with most of the measurements being around 1.5 meters. During the March winter sample of 2006, ice was solid for 0.6 meters and snow was 1.5 feet deep and lay upon the entire surface of the ice. In April 2006, the ice was one meter thick and had several layers.

Catchment Area (size of catchment, type of geology) – The watershed draining into Manning Meadow Reservoir is 1,186 acres in size and is located on the Sevier Plateau which is within the Southern High Plateaus Section, an extensive unbroken expanse of extrusive igneous rock. These lava capped plateaus contain flat-lying flows of andesite, rhyolite, latte, and basalt, together with extensive deposits of volcanic ash and agglomerate (Stokes 1986). Most of the reservoir is located in a north-south oriented steep valley that is about 1.5 mile wide at the top and the valley at the upper end of the reservoir opens up into a broad, 3000 foot-wide, low gradient valley bottom surrounded by steep mountains about 1000 feet above the valley floor. The predominant vegetation types in the valley bottom are sagebrush/mountain brush with sedges in the valley floor wetlands and pockets of aspen and conifer on the steep side slopes. According to Bronmark and Hansson (2005), a small catchment area, particularly within conifer forest, is likely to have low nutrients since soils have low productivity and rainwater has a short distance to reach the lake.

Figure 7. Manning Meadows Reservoir: pH vs. Depth



pH – Most of the pH values for water samples collected in Manning Meadow Reservoir are between 7.3 and 8.5. The only time pH was very high was in surface three meters in August of 2000 which went above a pH of 10. As seen in Figure 5, pH tends to be stratified during the summer season particularly in August. The pH of the streams flowing into the reservoir lies within a range of 7.0 and 8.4. A high reading of 9.4 is recorded for Timber Creek in September 2006. The pH of the water flowing in Manning

Creek is in the range of 6.9 and 7.8. Manning Meadow Reservoir is alkaline and is typical of most lakes. According to Bronmark and Hansson (2005), the majority of lakes have a pH between 6 and 9.

Nutrients – Table 2 contains a summary of exceedances and Table 3 contains the dissolved and total phosphorus and nitrogen concentrations in Manning Meadow Reservoir for samples collected since 1992. For samples collected at all depths since 1992, the average concentration of total phosphorus as P at the reservoir's surface (21) is 0.025 mg/l, above the thermocline (23) is 0.025 mg/l, below the thermocline (27) is 0.083 mg/l, and just above the bottom (29) is 0.191 mg/l. For all samples collected, nitrogen as dissolved nitrite+nitrate was well below the standard of 4.0 mg/l and most of the samples (82%) did not detect nitrogen.

Table 2. Summary of Total Phosphorus exceedances and concentrations.

Time Period	**Number of Exceedances**	**Number of Samples**	**Percent of Exceedances**	**Average Concentration (mg/l)**
1992 – 2005	47	60	78.3	0.075
2006	17	19	89.5	0.095
1992 - 2006	64	79	81.0	0.080

It may be inferred from these data two key characteristics of the reservoir. The first characteristic is the significance of internal nutrient loading into the reservoir (specifically total phosphorus). Internal nutrient loading is an important factor in evaluating the causes of water quality impairment as well as in establishing practical solutions and reasonable timelines for improvement. Internal loading can be shown by the fact that phosphorus concentrations in samples collected below the thermocline (27 and 29) are all much higher than those collected above the thermocline. The second characteristic demonstrated by these data is the high proportion of dissolved phosphorus to total phosphorus. In fact for several samples the data indicate the dissolved portion is actually higher than the total which is likely due to the small amount of uncertainty associated with the analytical analysis. The dissolved form of phosphorus typically originates from biological sources including microbial decomposition. Therefore the relatively higher concentrations of phosphorus in the lower levels of the reservoir and the preponderance of phosphorus in the dissolved form indicate that internal nutrient loading is an important factor contributing to DO impairment in Manning Meadows Reservoir.

Table 3. Manning Meadows Reservoir (STORET 5945040) - Nutrients by depth level.

	Dissolved Total Phosphorus as P (mg/l)				Total Phosphorus as P (mg/l)					D-NO2+NO3, N (mg/l)			
Date	**21**	**23**	**27**	**29**	**21**	**23**	**27**	**29**	**Average**	**21**	**23**	**27**	**29**
06/24/1992	0.058	0.045	0.084	0.346	0.037	0.029	0.054	0.396	0.129	0.12	0.20	0.07	ND
08/05/1992	0.019	0.018	0.103	0.187	0.039	0.020	0.106	0.219	0.096	ND	ND	ND	0.03
07/06/1994	0.062	0.127	0.116	0.038	0.026	0.027	0.045	0.111	0.052	ND	ND	ND	ND
08/23/1994	0.028	0.024	0.129	0.168	0.044	0.033	0.161	0.205	0.111	ND	ND	ND	ND
03/08/1995	---	---	---	---	---	---	---	ND		---	---	---	---
07/01/1996	0.020	0.020	0.030	0.090	0.020	0.020	0.030	0.140	0.053	ND	ND	ND	0.03
08/21/1996	0.030	0.030	0.060	0.110	0.020	0.020	0.060	0.120	0.055	ND	ND	0.02	0.04
07/09/1998	ND	ND	0.022	0.048	0.025	0.031	0.025	0.089	0.043	ND	ND	ND	ND
09/08/1998	ND	ND	0.077	0.039	0.027	0.023	0.091	0.172	0.078	ND	ND	ND	ND
06/20/2000	0.024	0.022	0.031	0.148	0.028	0.028	0.043	0.330	0.107	ND	ND	0.10	---
08/15/2000	ND	ND	0.032	0.056	0.022	0.040	0.023	0.064	0.037	0.10	ND	ND	0.10
06/19/2002	0.027	0.038	0.032	0.073	---	---	---	---		ND	ND	ND	ND
08/28/2002	---	0.032	ND	ND	0.046	0.044	0.034	0.062	0.047	ND	ND	ND	ND
06/08/2004	0.026	0.026	0.024	0.026	0.033	0.036	0.027	0.031	0.032	ND	ND	ND	ND
07/21/2004	ND	ND	0.077	0.192	ND	ND	0.093	0.256	0.175	ND	ND	ND	ND
08/11/2004	ND	ND	0.072	0.118	ND	ND	0.083	0.145	0.114	ND	ND	ND	ND
09/08/2004	ND	0.020	0.182	0.268	0.026	0.020	0.194	0.323	0.141	ND	ND	ND	ND
03/14/2006	0.033	0.026	0.052	0.199	0.031	0.032	0.073	0.320	0.114	1.00	0.36	0.50	0.24
04/17/2006	Unsafe Ice Conditions - No samples taken												
05/30/2006	Unsafe Ice Conditions - No samples taken												
06/26/2006	ND	0.022	0.058	0.115	ND	0.020	0.087	0.163	0.090	ND	ND	ND	ND
07/25/2006	ND	ND	0.048	0.083	0.026	0.034	0.118	0.172	0.088	ND	ND	ND	ND
08/21/2006	ND	ND	0.114	0.248	0.027	0.027	0.167	0.313	0.134	ND	ND	ND	ND
09/15/2006	ND	ND	0.052	0.123	0.028	0.025	0.136	---	0.063	ND	ND	ND	ND

Note: ND means Non-detect. Red highlighted values exceed pollution indicator limit (0.025 mg/l for phosphorus and 4.0 mg/l for NO3+NO2).

Dissolved and total phosphorus and nitrogen concentrations in water samples collected in streams flowing into Manning Meadow Reservoir are shown in Table 4 and those values that are non-detect or above the State indicator value of 0.05 mg/l are indicated. For streams above the reservoir, the average concentration of total phosphorus as P is 0.044 mg/l. During the 2006 sampling period, 50% of the samples in Timber Creek are above the total phosphorus indicator value of 0.05 mg/L. All of the samples collected in Manning Creek above the reservoir are below the total phosphorus State indicator value. The ratio of dissolved total phosphorus to total phosphorus indicates that most of the phosphorus from Timber Creek is in the dissolved fraction and most of the phosphorus in Manning Creek is from the sediment-born fraction.

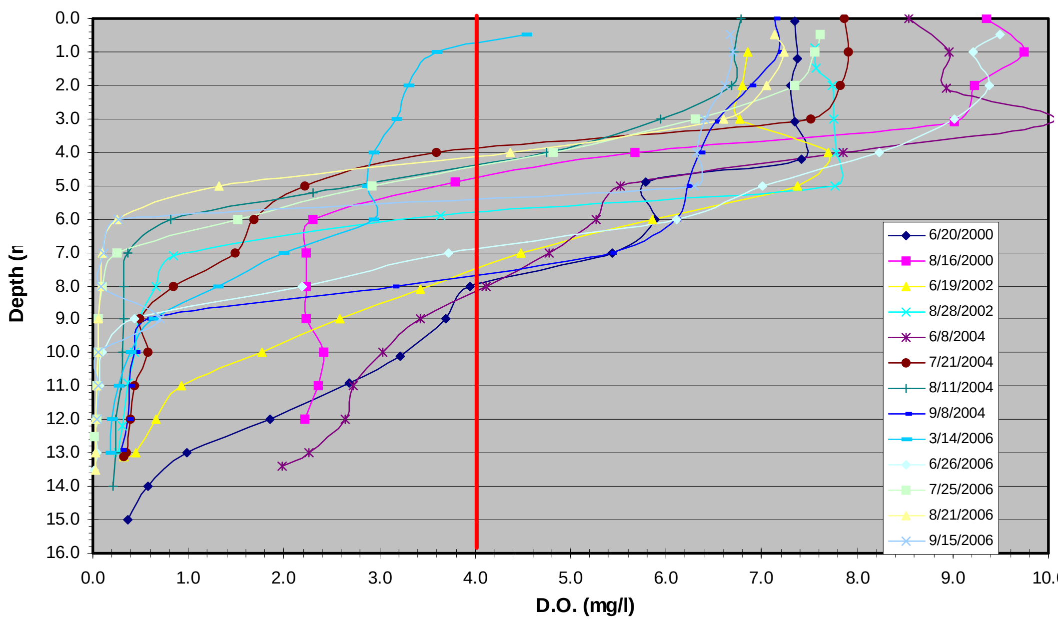
Table 4. Nutrient data for streams at Manning Meadow Reservoir.

Location	Date	Dissolved Total Phosphorus (mg/l)	Total Phosphorus (mg/l)	DP:TP Ratio	Dissolved Nitrite + Nitrate as N (mg/l)
Timber Ck above Manning Meadow Res.	07/06/1994	0.067	0.034	1.97	---
Timber Ck above Manning Meadow Res.	08/21/1996	0.060	0.040	1.50	---
Timber Ck above Manning Meadow Res.	07/09/1998	0.024	0.034	0.71	---
Timber Ck above Manning Meadow Res.	09/08/1998	0.035	0.034	1.03	---
Timber Ck above Manning Meadow Res.	06/20/2000	0.067	0.052	1.29	ND
Timber Ck above Manning Meadow Res.	08/28/2002	ND	0.075		ND
Timber Ck above Manning Meadow Res.	06/08/2004	0.025	0.021	1.19	ND
Timber Ck above Manning Meadow Res.	07/21/2004	0.032	0.035	0.91	ND
Timber Ck above Manning Meadow Res.	08/11/2004	0.035	0.031	1.13	ND
Timber Ck above Manning Meadow Res.	09/08/2004	0.036	0.035	1.03	ND
Timber Ck above Manning Meadow Res.	09/29/2005	ND	0.020		ND
Timber Ck above Manning Meadow Res.	11/16/2005	ND	0.022		ND
Timber Ck above Manning Meadow Res.	03/14/2006	No Access to Water			
Timber Ck above Manning Meadow Res.	04/17/2006	No Access to Water			
Timber Ck above Manning Meadow Res.	05/30/2006	ND	0.023		ND
Timber Ck above Manning Meadow Res.	06/26/2006	0.028	0.233	0.12	ND
Timber Ck above Manning Meadow Res.	07/25/2006	ND	0.030		ND
Timber Ck above Manning Meadow Res.	08/21/2006	0.035	0.050	0.70	ND
Timber Ck above Manning Meadow Res.	09/15/2006	0.049	0.066	0.74	ND
Timber Ck above Manning Meadow Res.	10/03/2006	0.031	0.028	1.11	ND
Manning Ck above Manning Meadow Res.	03/14/2006	No Access to Water			
Manning Ck above Manning Meadow Res.	04/17/2006	No Access to Water			
Manning Ck above Manning Meadow Res.	05/30/2006	ND	ND		ND
Manning Ck above Manning Meadow Res.	06/26/2006	ND	ND		ND
Manning Ck above Manning Meadow Res.	07/25/2006	ND	0.047		ND
Manning Ck above Manning Meadow Res.	08/21/2006	Not enough water to take readings or sample.			
Manning Ck above Manning Meadow Res.	09/15/2006	ND	0.040		ND
Manning Ck above Manning Meadow Res.	10/03/2006	ND	0.023		ND

Note: ND means Non-detect. Red highlighted values exceed pollution indicator limit (0.05 mg/l for phosphorus and 4.0 mg/l for NO3+NO2).

Oxygen –The dissolved oxygen profiles for Manning Meadow Reservoir shows stratification occurring throughout the year. Dissolved oxygen is above the State standard of 4.0 mg/l between the surface and 4 to 8 meters in depth and the dissolved oxygen drops rapidly at 3 to 5 meters from the surface. The March 2006 profile is an exception and has dissolved oxygen below State standards throughout almost the entire water column.

Figure 7. Manning Meadows Reservoir: Dissolved Oxygen vs. Depth



For all the sample events since 2000, 61 percent of the samples at 1.0 -meter intervals in the water column were below the dissolved oxygen standard of 4.0 mg/l. For the profiles measured in 2006, 66 percent of the samples at 1.0-meter intervals in the water column were below 4.0 mg/l.

Macrophytes – During sampling in 2006, macrophytes were seen in the shallow water of the reservoir near the Manning Creek inlet. Macrophytes were not seen in other areas of the reservoir, probably because the reservoir was too deep and light cannot penetrate very far into the water making it difficult for macrophytes to grow.
Macrophytes and algae are the only aquatic organisms that need light as their energy source. Since light intensity decreases with depth, the depth at which macrophytes grow is dependent upon the amount of light that penetrates through the water. Angiosperms need about 15% of the amount of light at the surface (Bronmark and Hansson 2005). Manning Meadows Reservoir has an average depth of 5.5 meters and a maximum depth of 19 meters. Much of the reservoir bottom would not be conducive for macrophyte growth based on the relationship between secchi depth and maximum depth of growth of angiosperms shown by Chambers and Kaiff (1985) and Bronmark and Hansson (2005). The relationship indicates that with a secchi depth of 1.5 meters the maximum depth of

angiosperm growth would be less than 3 meters. However, plants can overcome the depth limitation by growing tall and reaching light near the surface while the roots are in the lake bottom below the area of minimum light requirements (Bronmark and Hansson 2005).

Algae –During the 2006 and 2007 sampling events, chlorophyll a, uncorrected for pheophytin ranged from 2.4 to 8.5 ug/l with the largest value in August and the lowest value in March. A seasonal trend is observed in the data where algae concentrations are much less during the winter and increases as water temperatures rise in the summer. While sampling in July and August 2006, a heavy algae bloom that looked green and mossy with particles in it, was seen in Manning Meadows Reservoir.

A taxonomic survey of phytoplankton was conducted on Manning Meadow Reservoir from a sample of the water column collected in August 2006. The results of this sample compared to those in the Judd inventory (1997) is presented in Table 5.

Table 5. Diversity measurements for Manning Meadows Reservoir.

Diversity Measure	**Judd (1997)**	**2006 Sample**
Shannon-Weaver Index	0.28	1.10
Species Evenness	0.16	0.48
Species Richness	0.20	1.65

According to these measurements the phytoplankton community in Manning Meadow Reservoir has increased in diversity and richness over the 10 years between sampling events although this could also be attributable to the time of year the samples were collected. As the summer growing season progresses the assemblage of phytoplankton changes in response to climactic variables and competition between species. The community can shift from relatively diverse to only a few species in a short period of time in response to an algal bloom. Therefore these data may not be truly reflective of environmental changes in the reservoir.

Discussion – Pollution from point sources and nonpoint sources can enter a lake and cause water quality problems (Olem and Flock 1990, 94). Non-point sources of pollution can contaminate lakes through runoff and groundwater. Runoff can carry sediment and fertilizers from roads, lawns, and agricultural wastes such as livestock manure. Nutrients and bacteria can enter a lake through malfunctioning septic systems. When bacteria consume nutrients, dissolved oxygen is consumed, particularly in the hypolimnetic zone. This can result in low dissolved oxygen levels, fish kills, odors, and noxious conditions. In addition, nutrients act as a fertilizer and can stimulate excessive growth of algae and macrophytes that may contribute to additional loss of dissolved oxygen.

A review of the potential point source and nonpoint source pollution within the watershed draining into Manning Meadow Reservoir indicates that there are no point sources of pollution. Non-point sources of pollution include livestock and wildlife grazing in the watershed and from some limited areas of soil disturbance. There is some soil disturbance by livestock and wildlife in the meadow above the reservoir. No grazing appears to be occurring in the boggy area of Manning Creek just above the reservoir and a wire fence is in place to keep livestock out. Sedimentation of Manning Creek is evident by the silt that is deposited in the boggy area. The source of the silt may be from several sources in the watershed draining into Manning Creek above the reservoir. For the most part, the swale/channel in Manning Creek meadow above the reservoir appears to be fairly stable with occasional bare soil. Possible sediment sources that are located on private land include:

- Numerous trails and routes caused by trucks and ATVs some of which cross Manning Creek and the southern tributary of Manning Creek.
- Few bare spots in the upland and a few bare spots in spring areas caused by wildlife and livestock.

No sources of pollution were identified from Timber Creek and the egg collection station appears to be functioning well and not contributing sediment to the stream. A parking pad near the egg collection station consisting of two parking spaces is on relatively flat ground and is not considered to be contributing sediment to the reservoir. A boat launch near the dam has a small area of soil disturbance consisting of a compacted two-track dirt path that leads to the reservoir. Most of the shoreline is well-vegetated and is not contributing sediment into the reservoir. A dirt road is located on the west side of the reservoir and has proper drainage structures and is maintained by the county. It does not appear that upland forested areas are contributing to accelerated erosion or sedimentation of the reservoir. A relatively new vault toilet has been installed near the dam along with a vehicle turnout. The toilet is in good condition and does not appear to be leaking.

Researchers of the U. S. Geological Survey (Winter etal.1998) summarized ground water and surface water processes affecting chemicals in lakes and wetlands and an excerpt from their discussion that applies to nutrients is presented below.

> "Lakes and wetlands also have distinctive biogeochemical characteristics with respect to their interaction with ground water. The chemistry of ground water and the direction and magnitude of exchange with surface water significantly affect the input of dissolved chemicals to lakes and wetlands. In general, if lakes and wetlands have little interaction with streams or with ground water, input of dissolved chemicals is mostly from precipitation; therefore, the input of chemicals is minimal. Lakes and wetlands that have a considerable amount of ground-water inflow generally have large inputs of dissolved chemicals. In cases where the input of dissolved nutrients such as phosphorus and nitrogen exceeds the output, primary production by algae and wetland plants is large. When this large amount of plant material dies, oxygen is used in the process of decomposition. In some cases the loss of oxygen from lake water can be large enough to kill fish and other aquatic organisms.
>
> The magnitude of surface-water inflow and outflow also affects the retention of nutrients in wetlands. If lakes or wetlands have no stream outflow, retention of chemicals is high. The tendency to retain nutrients usually is less in wetlands that are flushed substantially by throughflow of surface water. In general, as surface-

> water inputs increase, wetlands vary from those that strongly retain nutrients to those that both import and export large amounts of nutrients. Furthermore, wetlands commonly have a significant role in altering the chemical form of dissolved constituents. For example, wetlands that have throughflow of surface water tend to retain the chemically oxidized forms and release the chemically reduced forms of metals and nutrients."

Most of the surface water flowing into the reservoir is from Timber Creek in which most of the phosphorus is in the dissolved fraction. This indicates that ground water is the most likely source of this inflow water. With very little evidence of man-made phosphorus sources in Timber Creek, it is likely that the phosphorus entering the lake is mostly from natural sources of ground water.

In the following discussion, Bronmark and Hansson (2005) describe dissolved oxygen conditions in autumn and winter that are typical of shallow lakes.

> "In autumn, the amount of solar energy reaching the lake is reduced and water temperatures will decrease. Eventually, the lake water will overturn and oxygenated water circulates down to the deeper strata (Fig. 2.5). At the formation of an ice cover during winter, the exchange of oxygen with the atmosphere will be blocked. If the ice is transparent, there will be a considerable production of oxygen by photosynthesizing algae immediately under the ice, whereas in deeper layers oxygen-consuming decomposition processes will dominate. The amount of dissolved oxygen will thus decrease with increasing depth during the winter and be particularly low close to the bottom (Fig. 2.5). If the ice is covered by a thick layer of snow, photosynthesis and oxygen production will be almost completely suppressed because of the lack of light. If this continues for a long period the oxygen in the lake may be completely depleted, resulting in massive fish mortality. This is called '*winterkill*' and is especially common in shallow, productive ponds and lakes where decomposition of large quantities of dead organisms consumes a lot of oxygen."

The changes in dissolved oxygen described above are different than the lake processes in Manning Meadows reservoir. During the summer, the lake has temperature stratification at about four meters and sometime between October and March, the water temperatures become very cold throughout the profile. A rapid decrease in dissolved oxygen occurs from the 7-meter depth to the bottom throughout the year. In March in the middle of the ice-covered season, the lake has very low dissolved oxygen throughout the water profile. This is likely caused by the decomposition of organic matter and the deep snow and ice cover.

7.0 Source Assessment

This section identifies whether load reductions are necessary, and if so, what would be an appropriate margin of safety for limits on sources of pollution while considering the seasonal changes of the parameters of concern.

The results of the water quality data and land management activities in the watershed indicate that natural processes are causing dissolved oxygen impairment in Manning Meadows Reservoir. The primary sources of phosphorus loading into the Reservoir include internal loading from bottom sediments and groundwater contributions to Timber Creek.

As discussed in Section 6, dissolved oxygen impairment appears to be naturally occurring and not caused by anthropogenic sources for Manning Meadows Reservoir within the Fishlake National Forest. Since anthropogenic activities have not caused the impairment, Manning Meadows Reservoir is recommended to be placed in Category 4C of the State of Utah's 303d List as not impaired by a pollutant.

8.0 Best Management Practices

Although Manning Meadows Reservoir has been determined to not be impaired due to anthropogenic causes several recommended projects are included to help guide land management efforts to preserve and improve current water quality conditions

Recommended practices:

- On private land, consolidate routes in the watershed draining into Manning Creek and tributaries in order to reduce the numerous trails and routes caused by trucks and ATVs some of which cross Manning Creek and the southern tributary of Manning Creek. Avoid wet areas and avoid crossing Manning Creek or use small bridges to cross. Move cattle frequently to keep livestock from congregating and creating denuded areas in the uplands and springs.
- On National Forest lands, maintain the fence that keeps livestock out of the wetland area of Manning Creek just above the reservoir. Designate areas where dispersed camping should occur and control soil erosion from these areas. Limit vehicle access to the reservoir to one boat launch and create proper drainage for this route to control erosion and sediment movement. Where soil erosion appears to be causing sediment to enter the reservoir, use best management practices to control erosion such as planting seed and mulching bare soil areas, and placing barriers such as branches, rocks, and in unwanted user created paths.

The Forest Service would be responsible for implementing work on National Forest lands but when implementation would occur would depend upon available funding and Forest Service priorities.

Other means of addressing the dissolved oxygen deficit is described below but is not recommended for this reservoir. Several approaches for increasing dissolved oxygen in lakes are described in Baker et al. (1993). Low levels of dissolved oxygen can occur in natural and culturally-altered lake conditions primarily in the hypolimnion during long periods of ice or snow and in dense macrophyte beds at night or following long periods of cloud cover. Approaches to alleviating low dissolved oxygen problems include decreasing the quantity of organic matter decomposing in the lake, increasing photosynthesis, destratifying the lake, and directly aerating the lake.

Several techniques can been used to increase dissolved oxygen and each has their limitations. Pump and baffle systems, consisting of water pumped on shore through a set of baffles, are effective at increasing dissolved oxygen but freeze-up during the winter can cause ice buildup that may in turn cause the baffles to be ineffective or become top heavy and fall over. The system must be checked daily to ensure proper operation. Artificial circulation eliminates thermal stratification and produces lake-wide mixing. The technique is best used in lakes that are not nutrient limited because nutrient concentrations are often higher in the hypolimnion and mixing can stimulate increased algae growth. In addition, artificial circulation is not a viable option for coldwater fish species that use the hypolimnion as a thermal refuge during summer. Hypolimnetic aerators may be used to increase dissolved oxygen in the hypolimnion without disturbing thermal stratification. However, hypolimnetic aerators require a large hypolimnion to work properly and are generally ineffective in shallow lakes or ponds. Direct oxygen injection into the hypolimnion has been effective at raising dissolved oxygen levels. Snowplowing that removes at least 30 percent of the snow is effective in preventing winterkill in shallow lakes with abundant rooted macrophytes. It has been noted that even thin layers of snow can greatly decrease light penetration which decreases primary productivity and can lead to dissolved oxygen depletion. An important option for lakes with dissolved oxygen problems is to mange the fisheries for species that tolerate relatively low levels of dissolved oxygen or that do not inhabit areas of the lake that experience oxygen depletion such as the hypolimnion (Baker et al.).

In the late 1970s through the early 1990s, the Wasatch-Cache National Forest installed mechanical circulation devices, bottled oxygen and air diffusers on several lakes to try to break down the summer thermal stratification and to decrease the amount of time that the lower lake depths are devoid of dissolved oxygen, or to directly oxygenate the lake water. Aerators powered by solar panels were installed on Marsh Lake; barrel-type wind aerators were installed on Sargent Lake, an unnamed lake east of Stateline Reservoir, Graham Reservoir, and Teapot Lake; bottled oxygen was hauled into a couple small lakes near Stateline Reservoir and diffused into the lake; and in partnership with Phillips Petroleum, air was diffused throughout Quarter Corner Lake using air hoses attached to the compressor plant located at a nearby oil pad. At Quarter Corner Lake, a fishing pier was installed in anticipation of a year-round fishery but oxygen was still limited in the lake. The Utah Division of Wildlife Resources still stocks trout in the lake for a put-and-take fishery.

Oxygen monitoring in the lakes showed mixed results. The ability of the wind powered circulators to bring about a complete mixing of the lakes that otherwise would be thermally stratified has not been realized on these lakes. The effect on Sargent Lake and Teapot Lake is that circulation had little effect on the oxygen/temperature profile yet had a significant effect on the dissolved oxygen during the summer. However, Teapot Lake has never been able to overwinter fish. Marsh Lake had a significant change in the summer temperature profile but little change in the dissolved oxygen profile. The winter dissolved oxygen in Marsh Lake increased after the first year but is most likely the result of the breaching of the irrigation dam at the same time that the circulators were running and the aquatic vegetation in the lake decreased by about one-half. These efforts were abandoned in the early 1990s because of the very difficult environmental conditions for operation and maintenance, the marginal results of the efforts, and the high costs to the low benefits that were realized from the projects.

REFERENCES

Baker, J.P., H. Olem, C.S. Creager, M.D. Marcus, and B.R. Parkhurst. 1993. Fish and Fisheries Management in Lakes and Reservoirs. EPA 841-R-93-002. Terrene Institute and U.S. Environmental Protection Agency, Washington, D.C.

Bronmark, Christer and Lars-Anders Hansson. 2005. The Biology of Lakes and Ponds. Oxford University Press.

Judd, H.J. 1997. Utah's Lakes and Reservoirs, An Inventory and Classification of Utah's Priority Lake and Reservoirs. Utah Department of Environmental Quality, Division of Water Quality.

Kent State. 2005. Internet site http://dipin.kent.edu.tsi.htm, The Great North American Secchi Dip-In. excerpted and modified from Carlson, R.E. and J. Simpson. 1996. A Coordinators Guide to Volunteer Lake Monitoring Methods. North American Lake Management Society. 96 pp.

Olem, H. and G. Flock, eds. 1990. Lake and Reservoir Restoration Guidance Manual, 2nd edition. EPA -440/4-90-006. Prep. by N. Am. Lake Manage. Soc. for U.S. Environ. Prot. Agency, Washington DC.

Stokes, William Lee. 1986. Geology of Utah. Utah Museum of Natural History, University of Utah and Utah Geological and Mineral Survey, Department of Natural Resources. Salt Lake City ,Utah.

Utah, State of. 2005. Standards of Quality for the Waters of the State. R317-2, Utah Administrative Code. Utah Department of Environmental Quality, Division of Water Quality, Revised December 1, 2005.

Utah, State of. 2006. Utah's 2004 303(d) List of Impaired Waters. Utah Department of Environmental Quality, Division of Water Quality.

Utah, State of. 2007. Draft Water Quality Assessment Guidance. Utah Department of Environmental Quality, Division of Water Quality, August 31, 2007.

Winter, Thomas C., Judson W. Harvey, O. Lehn Franke, and William M. Alley. 1998. Ground Water and Surface Water A Single Resource. U.S. Geological Survey Circular 1139.