YANKEE MEADOW RESERVOIR

LIMNOLOGICAL ASSESSMENT OF WATER QUALITY

December 2008

Yankee Meadow Reservoir Water Quality Assessment Report
December 24, 2008

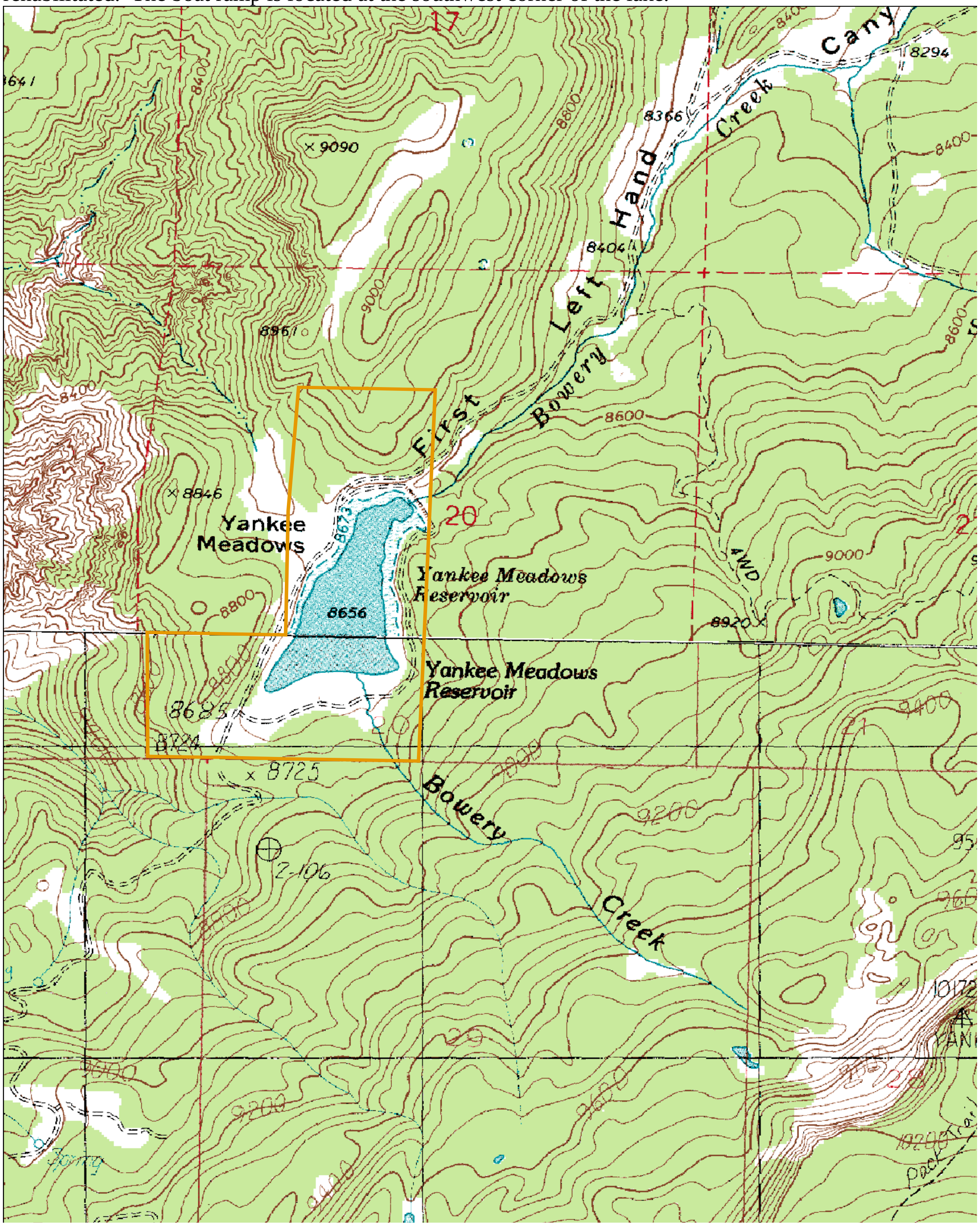
Yankee Meadow Reservoir is listed by the State of Utah as an impaired water body because dissolved oxygen and pH does not meet State water quality standards. In partnership with Utah Division of Water Quality (UDWQ), the Dixie National Forest (DNF) collected data from Yankee Meadow Reservoir from March 2006 through May 2007 to provide recent detailed water quality information to support a thorough analysis and assessment. The results of the water quality data and land management activities in the watershed indicate that DO criteria are fully supported and natural processes are causing exceedances of the water quality standard for pH in Yankee Meadow Reservoir. The primary sources of phosphorus loading into the Reservoir include internal loading from bottom sediments, and groundwater and native geology contributions to Bowery Creek.

Since anthropogenic activities have not caused the impairment, Yankee Meadows Reservoir is recommended to be placed in Category 4C of the State of Utah's 303d List as not impaired by a pollutant.

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 and water quality standards for the parameters of concern for the water body.
- Section 3.0: Discussion of whether the impairments are naturally occurring, 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: Summary.

Figure 1. Yankee Meadow Reservoir Location Map. Orange polygon around reservoir delineates Utah state land. The road shown along the south and east sides of the reservoir has been blocked and rehabilitated. The boat ramp is located at the southwest corner of the lake.



1.0 Introduction

Yankee Meadow Reservoir is a man-made impoundment of Bowery Creek in a high-elevation meadow located at 8,656 feet. The reservoir is owned and administered by the Utah Division of Wildlife Resources (DWR) while the water ownership and management is controlled by the Parowan Reservoir Company. The reservoir is located on the steep northwest face of the Markagunt Plateau, located on a bench above the Pink Cliff formation, but below the steep upper face of volcanic rock that caps the plateau. Yankee Meadow Reservoir is approximately 53 acres in size with a maximum depth of around 10 meters. Its main tributary is Bowery Creek from the southeast, but it also has a small tributary from the east near the dam. Estimates of water flows in Bowery Creek flowing into the reservoir taken in 2006-2007 range from a low of 0.8 cfs in March 2007 to a high of 3.2 cfs in July 2006. Bowery Creek is the reservoir's only outflow, flowing to the northeast. The outflow is controlled, and is typically shut off between November and April. Draw down of the reservoir from approximately May through September expose bare lake shore that is subject to erosion from wave action and precipitation until the reservoir fills again with spring snowmelt.

The watershed above the reservoir is approximately 1,625 acres, and except for the State owned lands immediately around the reservoir, is entirely within the Dixie National Forest. The watershed receives about 16 to 20 inches of precipitation annually with most in the form of snow in the winter. During the spring, runoff from snowmelt is the primary source of flow into the lake, with Bowery Creek being the primary contributor of water throughout the year. Summer thunderstorms also provide input into the reservoir. The watershed above the reservoir is at a complex slope of 21.9% from the high point of 10,520 feet to the reservoir, with an average stream gradient of 15.6%.

Bowery Creek originates from springs coming out of the volcanic rocks along the steep face of the Markagunt Plateau. It is predominantly a steep, cascading system made up of numerous small channels. As it approaches Yankee Meadows Reservoir, flows tend to spread out over the rocky alluvial fan that has formed at the base of the slope. The Utah DWR has constructed an artificial channel at the mouth of Bowery Creek to channelize the flow entering the reservoir and reduce velocities to develop fish spawning habitat for trout. The riparian reaches along Bowery Creek above the reservoir are very narrow, stable streams dominated by cobbles and boulders. They are predominantly aspen, mixed conifer, and spruce-fir systems with a narrow band of riparian grasses, forbs, and woody species scattered through the drainage. Bowery Creek below the reservoir flows through open sagebrush-grasslands and aspen-blue spruce communities while on the bench. The riparian plant community along Bowery Creek below the reservoir has been compromised by the controlled release of water from the reservoir. Since there is typically no flow from November through April each year, the stream system has developed intermittent characteristics. It is incised and widened, with predominantly bare banks through much of its length on the bench, and is further impacted from heavy livestock use and dispersed recreation. The system has lost much of its sedge and willow component.

The primary upland plant communities include aspen, mixed conifer, spruce, and alpine as the watershed gains elevation. Ground cover in the uplands is in good condition. The watershed has been impacted by fire suppression, with aspen and spruce-fir communities being overtaken by thick stands of mixed conifer, and spruce mortality due to the spruce beetle.

The lake is used for recreational fishing and boating, propagation of cold water species of game fish and aquatic life, and irrigation. Dispersed camping mainly occurs on the northwest end on a rise above FS road 049 and at the southwest end past the boat ramp off FS road 049. Vault toilets are located at each of these locations, and are a considerable distance from the shoreline. Previous vehicle access along the south and east shore has been blocked off by fencing and boulders for resource protection. People occasionally walk in to disperse camp in this area. No roads are located in the watershed above the reservoir. The Spruce Trail, a non-motorized trail, traverses across a small section of the upper watershed above the steep volcanic face. Livestock grazing is permitted in the watershed, but is restricted from the lake shore through fencing along the state lands boundary.

2.0 Water Quality Standards

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

The State of Utah has designated the waters within Yankee Meadow Reservoir, as well as its tributaries, as High Quality Waters – Category 1 (Utah DEQ 2005). Water quality is required by state regulation to be maintained at existing high quality. New point source discharges of wastewater are prohibited, and non-point sources are controlled to the extent feasible through implementation of best management practices or regulatory programs.

The beneficial use designations for Yankee Meadow Reservoir 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, including the necessary aquatic organisms in their food chain; and Class 4 – protected for agricultural uses (Utah DEQ 2005). Bowery Creek, which feeds Yankee Meadow Reservoir and is ultimately a tributary of Parowan Creek, has the same beneficial use designations as Yankee Meadow Reservoir (Utah DEQ 2005).

Table 1 presents the 2006 303(d) listing for Yankee Meadow Reservoir. A classification of Partial-Support (PS) for criteria for the aquatic life beneficial use support (i.e. Class 3A, 3B, 3C, 3D) means that "For any one pollutant (in this case, dissolved oxygen and pH), criterion was exceeded two times, and criterion was exceeded in more than 10% but not more than 25% of the samples" (Utah DEQ 2006). Table 2 shows Utah's dissolved oxygen criteria for class 3A waters, which is one of the impaired beneficial uses for Yankee Meadow Reservoir. For pH, the criterion is a range, and impairment occurs if samples fall below a reading of 6.5, or above a reading of 9.0.

Table1. Utah 2006 303(d) Listing for Yankee Meadow Reservoir.

Waterbody	Waterbody Size	Beneficial Use Impaired	Beneficial Use Support	Pollutant or Stressor
Yankee Meadow Reservoir	53 acres	3A Cold Water Species of Game Fish	PS (Partial-Support)	Dissolved Oxygen, pH

The listing methodology employed by Utah for dissolved oxygen to assess Class 3A (aquatic life) beneficial use involves evaluating the dissolved oxygen profile data to see what percent of the water column falls below the one day average value of 4.0 milligrams per liter. When dissolved oxygen is greater than 4.0 milligrams per liter for greater than 50% of the water column, a fully supporting status is assigned. If 50-75% of the water column is less than 4.0 milligrams per liter, a partial support designation is assigned. If less than 25% of the water column is above 4.0 milligrams per liter or higher, a non-supporting designation is assigned (Utah DEQ 2006).

Table 2. Utah's dissolved oxygen criteria for class 3A waters.

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 mg/l when early life stages are present. 5.0 mg/l when all other life stages present
1 day average	8.0/4.0 mg/l	Not to exceed 110% of saturation. 8.0 mg/l when early life stages are present. 4.0 mg/l when all other life stages present

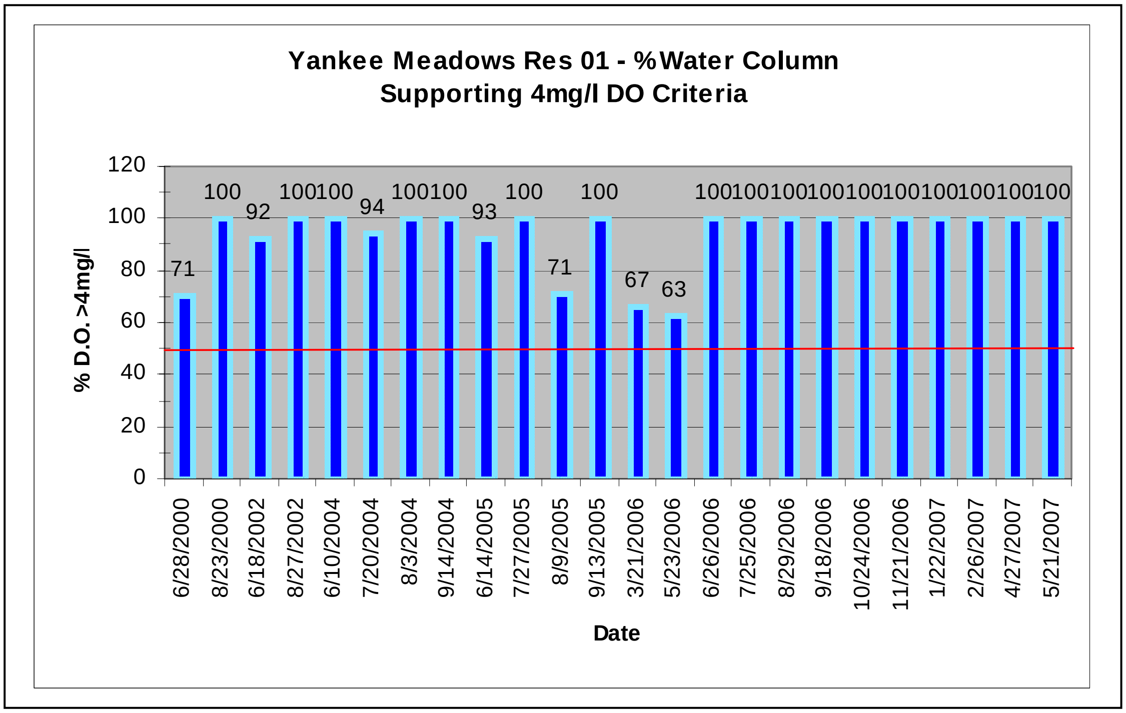
(R317-2; Standards of Quality for Waters of the State).

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 problematic condition, 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 a 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.

Graph 1 shows the percent of the water column supporting the 4.0 milligrams per liter dissolved oxygen criteria for its fisheries beneficial use, for all dates the reservoir has been sampled. All samples indicate full support of the dissolved oxygen criteria.

Graph 1. Percent of the water column supporting 4mg/l DO criteria for all dates data has been collected on Yankee Meadow Reservoir.

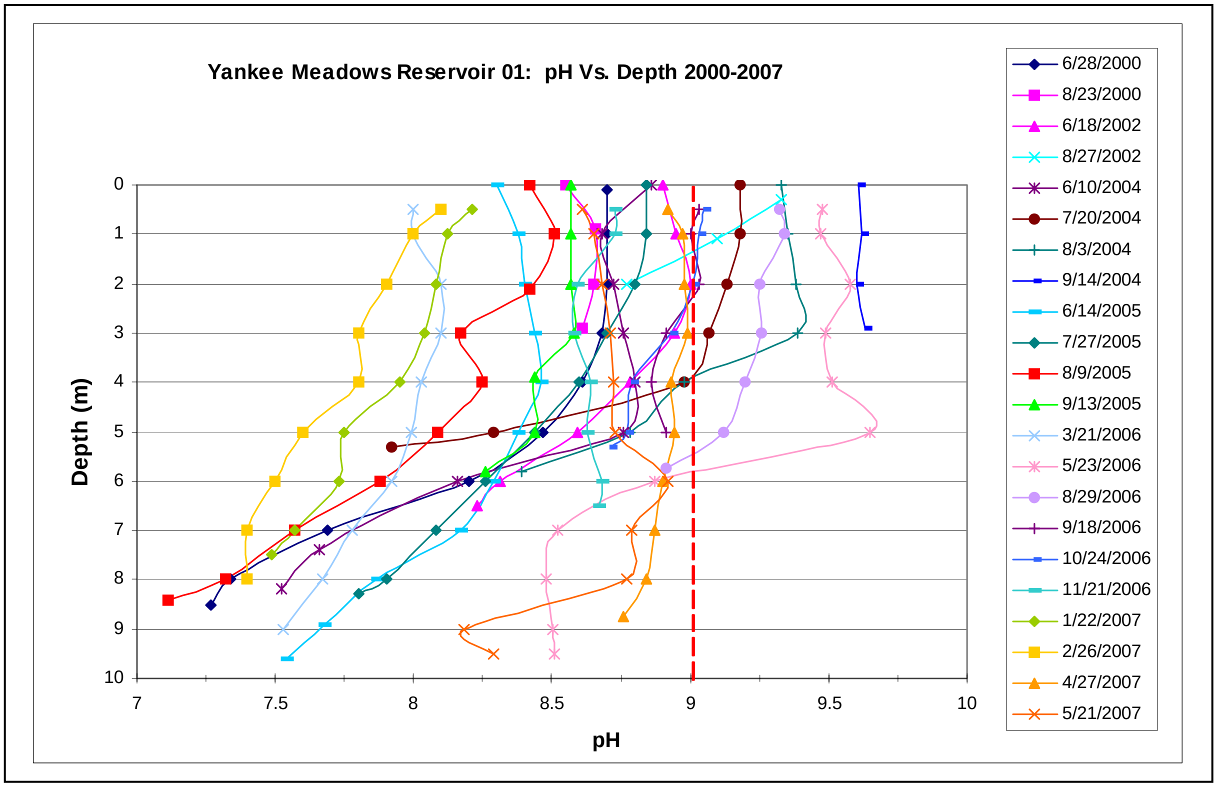


A stipulation of the dissolved oxygen criteria shown in Table 2 is that dissolved oxygen should not exceed 110% of saturation. Using a nomograph to convert dissolved oxygen in mg/l to percent DO such as the one in Horne and Goldman (1994), field data for July 2004, May 2006, and July 2006 indicate that this was exceeded (see Table 3).

Table 3. Field data for dissolved oxygen for months indicating supersaturation, and approximate percent saturation conversion.

Date	Depth (m)	DO (mg/l)	Temp °C	Approx. % Saturation of DO
7/20/2004	0	10.07	18.68	110%
7/20/2004	1	10.81	18.14	>115%
7/20/2004	2	10.52	17.62	>110%
7/20/2004	3	9.8	17.37	105%
7/20/2004	4	9.52	16.95	100%
7/20/2004	5	6.09	16.04	>60%
7/20/2004	5.3	3.89	15.86	40%
5/23/2006	0.5	11.24	15	115%
5/23/2006	1	11.2	14.7	>110%
5/23/2006	2	12	13.3	>115%
5/23/2006	3	11.73	13.1	115%
5/23/2006	4	12.89	12.4	>120%
5/23/2006	5	9.52	8.6	85%
5/23/2006	6	4.68	7.4	40%
5/23/2006	7	2.2	6.7	20%
5/23/2006	8	1.31	6.7	>10%
5/23/2006	9	0.85	6.6	>5%
5/23/2006	9.5	0.37	6.6	<5%
7/25/2006	0.5	7.98	21.3	90%
7/25/2006	1	8.46	21.26	>95%
7/25/2006	2	9.98	19.77	>110%
7/25/2006	3	11.11	19.15	>120%
7/25/2006	4	12.24	18.48	130%
7/25/2006	5	12.68	17.78	135%
7/25/2006	6	13.4	17.31	>140%
7/25/2006	7	12.95	16.71	>135%
7/25/2006	8	6.35	15.45	65%
7/25/2006	8.25	4.71	15.3	50%

Yankee Meadow Reservoir is also listed as partially supporting its Class 3A beneficial use for pH. As is the case for dissolved oxygen, a classification of Partial-Support (PS) for criteria for assessing aquatic life beneficial use support (i.e. Class 3A, 3B, 3C, 3D) means that "For any one pollutant, criterion was exceeded two times, and criterion was exceeded in more than 10% but not more than 25% of the samples" (Utah DEQ 2006). Utah's pH criterion for Class 3A waters is a range, and impairment occurs if samples fall below a reading of 6.5, or above a reading of 9.0. Graph 2 shows all of the pH data collected for Yankee Meadow Reservoir, from 2000 to 2007. No pH readings went below 6.5, but there were 8 months that had readings exceeding the pH of 9. With a total of 22 months sampled, approximately 36% of total pH samples have exceeded the pH criterion. Exceedences tend to occur in the summer months, but this is not consistent for every year that sampling has occurred in the summer. The months with exceedences included August 2002, July-September 2004, May 2006, and August-October 2006. Some of these dates correspond with periods of dissolved oxygen supersaturation.



3.0 Water Quality Targets/Endpoints

This section discusses whether the impairments are naturally occurring and the quantifiable targets or endpoints that will achieve water quality standards.

A review of potential pollution sources have identified a few that may be contributing to elevated total phosphorus and may result in dissolved oxygen deficits and elevated pH in the reservoir. These are discussed in Sections 4.0 and 5.0. The recommended endpoints for Yankee Meadow Reservoir are mean in-lake concentrations of total phosphorus of less than 0.025 mg/l, dissolved oxygen concentrations above 4.0 mg/l in greater than 50% of the water column, and pH within a range of 6.5 and 9.0.

4.0 TMDL

This section discusses which land management activities are contributing to the impairment, recommended practices 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.

Land management activities that contribute to the impairment are primarily soil-disturbing activities that are occurring in the immediate vicinity of the reservoir. Eliminating reservoir fluctuations from irrigation water release to prevent exposure and erosion of the lakeshore is not a feasible option given existing water rights. Recommended practices to reduce other sources of impairment around the reservoir include:

- Improve and maintain FS Road 049 and parking to control drainage and minimize soil movement to the lake shore.
- Designate areas for dispersed camping and control soil erosion from these areas.

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 include:

- The shoreline, which is bare most of the year from irrigation releases and subject to erosion from wave action and precipitation;
- FS Road 049 and associated road-side parking, which skirts the reservoir on the west shore, and the native- and gravel-surfaced parking area at the boat ramp on the south shore.
- Dispersed camping in the vicinity of the lakeshore creating areas of bare soil.

6.0 Technical Analysis

This section contains a description of water quality conditions at Yankee Meadow Reservoir.

Lake Morphology – Yankee Meadow Reservoir is somewhat rectangular in shape and is about 1,125 feet wide, 2,100 feet long, and has a mean depth of 15.7 feet.

Catchment Area - The watershed above the lake is about 1,625 acres. Upland groundcover is in good condition. However, the shore around Yankee Meadow Reservoir is impacted by yearly fluctuations in lake levels due to storage and release, creating a bare soil "bathtub ring" during most of the year that is further impacted by wave action.

Trophic State – Carlson's Trophic State Index (TSI) is used to determine the living biological material or biomass of a lake and uses a continuum of indices to predict the amount of biomass of the lake. The TSI for a lake can be 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, transparency should be used only if no other parameter is available (Kent State 2007).

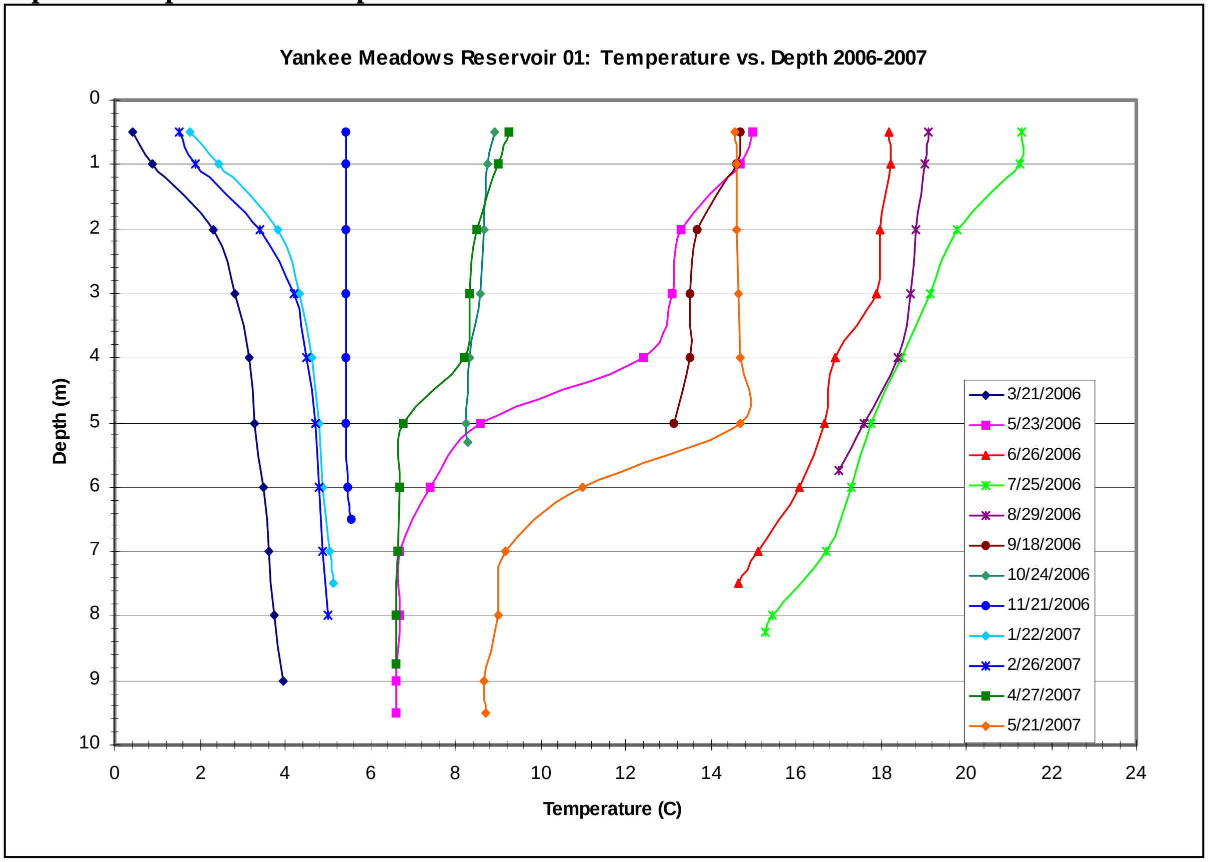
Carlson's TSI values classify northern temperate lakes into three general categories, oligotrophy, mesotrophy and eutrophy. Oligotrophic lakes are characterized by clear water and oxygen throughout the year in the hypolimnion (bottom water layer in a lake). Mesotrophic lakes are characterized by moderately 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 2007).

Based on chlorophyll-a sampling between 2006 and 2007, the trophic state in Yankee Meadow Reservoir seasonally fluctuates between mesotrophic and oligotrophic conditions. The reservoir was mesotrophic in late winter to early spring, becoming oligotrophic by June, then becoming mesotrophic in summer through fall except for a short period of oligotrophy in September, then becoming oligotrophic in winter.

Secchi depth and total phosphorus also place Yankee Meadow Reservoir primarily in the mesotrophic category.

Temperature – Temperature varies both seasonally and by depth based on measurements taken from 2006 through 2007 (Graph 2). A thermocline developed in April and May between about 4 and 6 meters, and was gone by June. October through March temperatures remained pretty consistent throughout the water column. Summer months show a steady decrease in temperature from surface to bottom. Warmest surface temperatures occurred in July 2006, at over 21^oC.

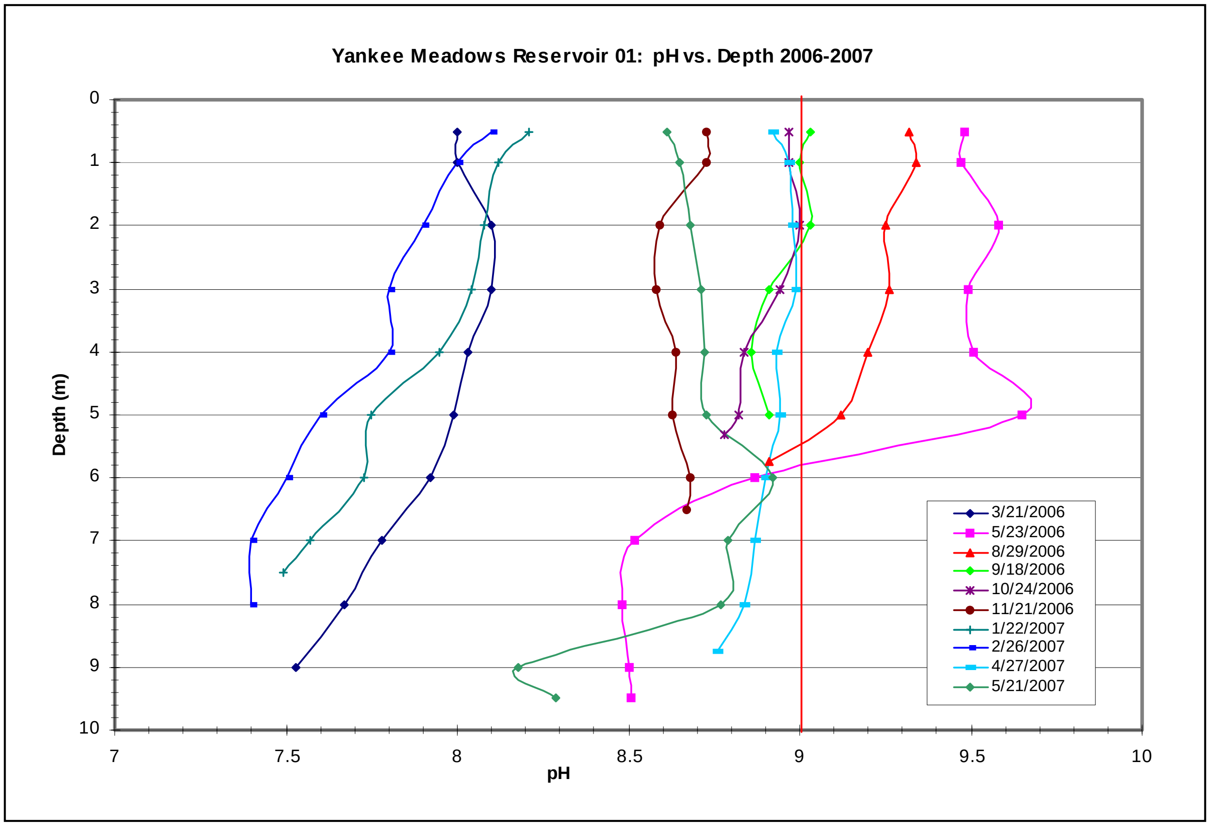
Graph 2. Temperature vs. Depth



Light (secchi depth) – From measurements taken in 2006 and 2007, the secchi depth ranged from 1.4 to 4.75 meters. The majority of the readings were around 2.5 meters in winter, early spring, and in late summer. Slightly improved clarity tended to occur in early summer and late fall. During the winter of 2006-2007, ice was approximately 16 to 20 inches thick and snow was approximately 8 to 15 inches with snowdrifts across the lake ice. No filamentous algae were observed in the water column at any time.

pH – Measurements taken in 2006 and 2007 show some variability in pH based on season and depth (Graph 3). The highest pH readings were in May through September, 2006, ranging from just over 9.0 to about 9.5, which exceeded the Utah Division of Water Quality's numeric criteria for pH for Class 3A waters. The numeric criterion for pH is a range of 6.5 to 9 (Utah DEQ 2005). The pH slowly declines to a low of 8.0 around March. The pH at the bottom of the lake ranges from 7.4 to 8.9 throughout the year. pH tends to decrease with depth in the water column, as can be expected due to increases in carbon dioxide from decomposition. During the two months that exhibited a strong thermocline (May 2006 and 2007), pH decreases dramatically in the hypolimnion due to CO_2 accumulation.

Graph 3. pH vs. Depth



Nutrients – Dissolved and total phosphorus were detected for most of the samples collected between 1992 and 2007, throughout most of the year (Refer to Table 4). There does not seem to be a clear pattern for time of year when levels are lowest or highest. The pollution indicator criterion of 0.025 mg/l was exceeded regularly for total phosphorus at all lake levels, but typically more often in the lower half of the lake. The same can be said for dissolved total phosphorus.

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 typically 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 almost a dozen 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 process in Yankee Meadow Reservoir.

Table 4. Yankee Meadows Reservoir - Total Phosphorus as P by depth level in lake.

Date	Dissolved Total Phosphorus as P (mg/l)				Total Phosphorus as P (mg/l)				D-NO2+NO3, N (mg/l)			
	21	23	27	29	21	23	27	29	21	23	27	29
6/16/1992	0.019	0.014	0.022	0.018	0.038	0.042	0.044	0.043	ND	ND	ND	ND
8/12/1992	0.018			0.025	0.038			0.042	ND			0.219
7/6/1994	0.012	0.023	0.023	0.018	0.034	0.028	0.036	0.069	ND	ND	ND	ND
8/16/1994	0.011	0.012	0.032	0.034	0.028	0.01	0.038	0.079	ND	ND	ND	ND
7/2/1996	0.02	0.01	0.02	0.02	0.03	0.03	0.03	0.03	ND	ND	ND	ND
8/14/1996	ND			0.01	0.01			0.03	ND			0.02
7/14/1998	ND	0.029	0.03	0.06	ND	ND	0.024	0.079	ND	ND	ND	ND
9/22/1998	ND			ND	0.036			0.021	ND			ND
6/27/2000	0.022				ND				0.1			
6/28/2000		ND	ND	0.057		ND	ND	0.06		0.1	0.1	0.1
8/23/2000	ND			ND	ND			ND	ND			ND
6/18/2002	0.024	0.023	0.03	0.058					ND	ND	ND	ND
8/27/2002	0.028			0.036	0.052			0.057	ND			ND
6/10/2004	ND	ND	0.031	0.112	0.02	0.02	0.05	0.12	ND	ND	ND	ND
7/20/2004	ND			ND	ND			ND	ND			ND
8/4/2004	ND			0.082	ND			0.075	ND			0.16
9/14/2004	0.028			0.024	0.023			0.025	ND			ND
6/14/2005	0.029	0.023	0.023	0.048	0.036	0.022	0.021	0.06	ND	ND	ND	ND
8/9/2005	ND	0.051	ND	0.063	0.02	ND	0.022	0.112	ND	0.16	0.12	ND
9/13/2005	ND			ND	0.039			0.024	ND			ND
3/21/2006	0.024	0.027	0.028	0.032	0.031	0.03	0.039	0.043	0.17	0.43	0.14	0.12
5/23/2006	ND	ND	0.027	0.024	ND	0.021	0.052	0.054	ND	ND	ND	ND
6/26/2006	ND	ND	ND	ND	ND	ND	ND	0.024	ND	ND	ND	ND
7/25/2006	ND	0.02	0.101	0.132	ND	0.023	0.121	0.149	ND	ND	ND	ND
8/29/2006	ND	ND	ND	0.027	0.026	0.037	0.026	0.042	0.25	ND	ND	ND
9/18/2006	ND	ND	ND	0.02	ND	ND	0.021	ND	ND	ND	ND	ND
10/24/2006	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
11/21/2006	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1/22/2007	ND	0.147	0.031	0.021	0.025	0.024	0.032	0.027	0.2	0.22	0.21	0.12
2/26/2007	0.023	0.023	0.023	0.028	0.024	0.024	0.025	0.027	0.3	0.27	0.21	0.19
4/27/2007	ND	ND	ND	ND	ND	ND	ND	0.023	ND	ND	ND	ND
5/21/2007	ND	ND	ND	ND	ND	0.021	ND	ND	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 Bowery Creek flowing into Yankee Meadow Reservoir are shown in Table 5 and those values that are non-detect or above the State indicator value of 0.05 mg/l are indicated. The average concentration of total phosphorus as P in Bowery Creek above the reservoir is 0.038 mg/l. During the 2006-2007 sampling period, 10% of the samples were above the total phosphorus indicator value of 0.05 mg/L. The ratio of dissolved total phosphorus to total phosphorus indicates that most of the phosphorus from Bowery Creek is in the dissolved fraction.

Table 5. Selected Data for streams above and below Yankee Meadows Res.

Date	D-Total Phosphorus (mg/l)	Total Phosphorus (mg/l)	D-NO2+NO3, N (mg/l)	Location
6/16/1992	0.021	0.025	0.169	Bowery Ck Abv
8/12/1992	0.03	0.034	0.208	Bowery Ck Abv
8/16/1994	0.064	0.019	0.47	Bowery Ck Abv
7/2/1996	0.03	0.03	0.15	Bowery Ck Abv
8/14/1996	0.03	0.03	0.21	Bowery Ck Abv
7/15/1998	0.035	0.039	0.45	Bowery Ck Abv
9/22/1998	0.029	0.033	0.4	Bowery Ck Abv
6/28/2000	0.066	0.058	0.6	Bowery Ck Abv
8/23/2000	0.039	ND	0.67	Bowery Ck Abv
6/18/2002	0.055		0.28	Bowery Ck Abv
8/27/2002	0.061	0.122	0.31	Bowery Ck Abv
6/10/2004	0.032	0.03	0.57	Bowery Ck Abv
7/20/2004	0.029	0.034	0.7	Bowery Ck Abv
8/4/2004	0.03	0.024	0.66	Bowery Ck Abv
9/14/2004	0.03	0.027	0.61	Bowery Ck Abv
6/14/2005	0.056	0.047	0.4	Bowery Ck Abv
8/9/2005	0.028	0.042	0.53	Bowery Ck Abv
9/13/2005	0.03	0.037	0.5	Bowery Ck Abv
9/27/2005	0.026	0.031	0.48	Bowery Ck Abv
11/15/2005	0.022	0.036	0.78	Bowery Ck Abv
5/2/2006	0.039	0.058	0.34	Bowery Ck Abv
5/22/2006	0.036	0.039	0.4	Bowery Ck Abv
5/22/2006	0.02	0.027	ND	Bowery Ck Bl
6/26/2006	0.037	0.037	0.55	Bowery Ck Abv
6/26/2006	0.048	0.068	ND	Bowery Ck Bl
7/25/2006	0.043	0.038	0.49	Bowery Ck Abv
7/25/2006	0.079	0.074	ND	Bowery Ck Bl
8/28/2006	0.048	0.044	0.46	Bowery Ck Abv
8/28/2006	0.034	0.043	ND	Bowery Ck Bl
9/20/2006	0.044	0.047	0.48	Bowery Ck Abv
9/20/2006	0.024	0.027	ND	Bowery Ck Bl
10/25/2006	0.031	0.026	0.48	Bowery Ck Abv
11/21/2006	0.029	0.028	0.49	Bowery Ck Abv
2/26/2007	0.029	0.032	0.49	Bowery Ck Abv
3/19/2007	0.032	0.028	0.45	Bowery Ck Abv
4/26/2007	0.026	0.033	0.39	Bowery Ck Abv
5/21/2007	0.024	0.025	0.38	Bowery Ck Abv
5/21/2007	ND	0.023	ND	Bowery Ck Bl

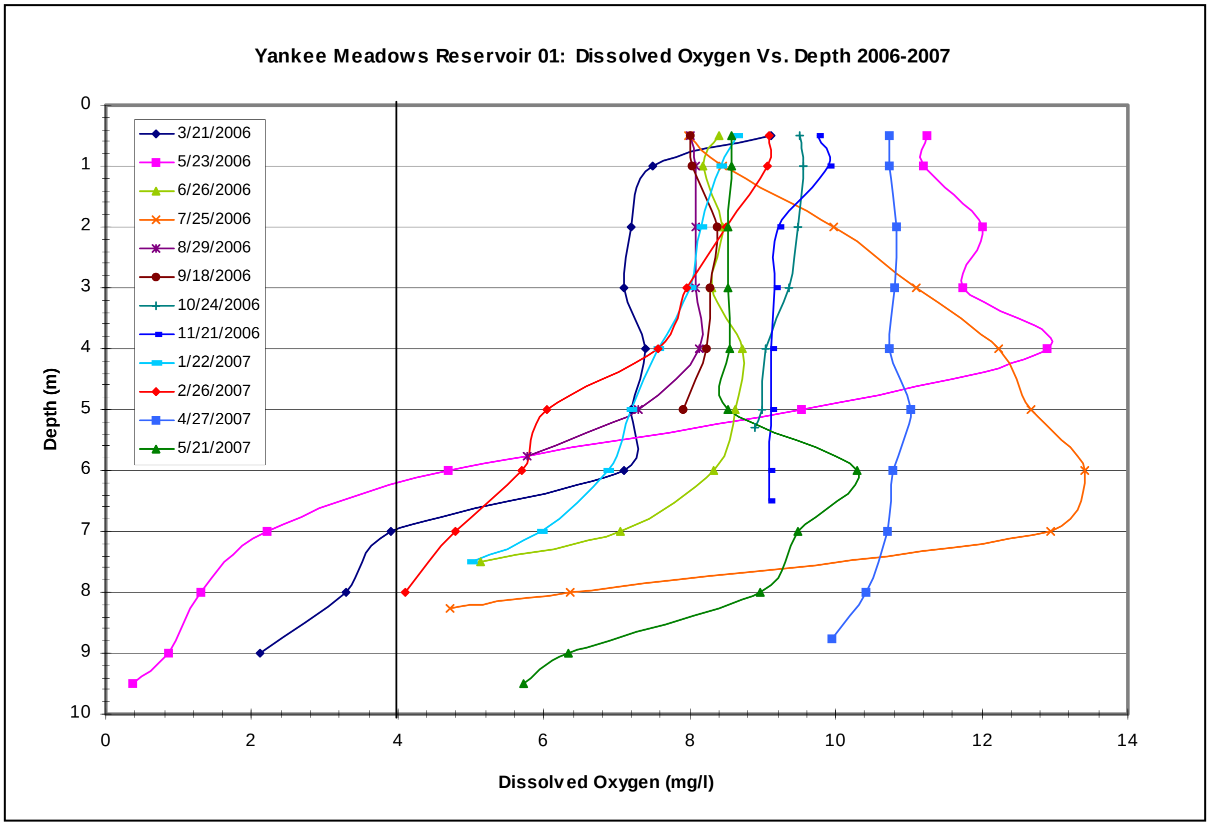
Note: ND means Non-detect. Red highlighted values exceed pollution indicator limit (0.05 mg/l for phosphorus and 4.0 mg/l for NO3+NO2).

Dissolved nitrate and nitrite were not detected in most of the lake samples, and in the samples where it was detected, the values were well below the pollution indicator value of 4 mg/l. Samples taken for Bowery Creek above the reservoir detected dissolved nitrate and nitrite in every sample, but they ranged from 0.15 to 0.78 mg/l, again well below the pollution indicator value of 4 mg/l.

According to Bronmark and Hansson (2005), most lakes unaffected by man have phosphorus concentrations between 0.001 to 0.1 mg/l and total nitrogen concentrations between .004 and 1.5 mg/l. Yankee Meadow Reservoir potentially fits this description, since almost all of the phosphorus readings are below 0.1 mg/l.

Oxygen – Dissolved oxygen concentrations fell below or approached the 4 mg/l dissolved oxygen criteria near the lake bottom in the months of February 2007, and March and May 2006 (Graph 4). For most months, DO tends to decrease with depth, with the least variation in oxygen levels through the water column occurring during months when the reservoir is at its shallowest.

Graph 4. Dissolved Oxygen vs. Depth



Macrophytes – Macrophytes did not seem to be present in any notable amounts, and those that were present were only observed along the southeast lakeshore. Personal observations by the Utah Division of Wildlife Resources were the same (personal communication with Chuck Chamberlain, 1/3/2008). A summary of Yankee Meadow Reservoir by the Utah Division of Water Quality indicated that there are large accumulations of macrophytes and algae later in the season (UDEQ 1997), but more recent observations indicate this is no longer a problem.

Algae – During the 2006 through 2007 sampling, chlorophyll-a, uncorrected for pheophytin, ranged from 0.7 to 6.8 ug/l, with the largest value occurring in October 2006. The lowest value occurred in June 2006. 2006 shows a spike in May 2006 of 5.6, then dropping to between 0.7 and 3.1 from June through September, peaking again in October, then declining again in the winter. Spring of 2007 however was not indicating a peak like there was in 2006, with readings between 2.7 and 3.2 ug/l during February through May 2007.

Discussion – Non-point sources of pollution can contaminate lakes through runoff and groundwater. Runoff can carry sediment and nutrients from roads, bare soil, 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. Excessive algae and macrophyte growth can create supersaturated oxygen conditions from photosynthesis during the day, which then plunges to low levels of dissolved oxygen at night from high levels of respiration and lack of photosynthesis, creating dramatic diel fluctuations.

pH is a measure of the acidity or alkalinity of water, and determines the solubility and biological availability of chemical constituents such as nutrients and heavy metals. When pollution results in higher algal and plant growth, pH levels may increase. This is because photosynthesis uses up dissolved carbon dioxide, which disassociates into carbonic acid in water. As carbon dioxide is decreased, the alkalinity of the water increases. These changes in pH can increase the solubility aggravate nutrient problems by of phosphorus, making it more available for plant growth.

There are no point sources of pollution within the Yankee Meadow Reservoir watershed nor any anthropogenic nonpoint sources.

There may be some natural influence on phosphorus inputs due to the volcanic geology of the watershed. Volcanic soils can have high concentrations of inorganic phosphorus. In contrast, Bowery Creek near it's confluence with Parowan Creek flows through sedimentary limestone, and during periods of the year when water from Yankee Meadow Reservoir isn't being released, flows originate entirely from a spring within this limestone formation. Sampling of Bowery Creek near the Dixie National Forest boundary (STORET # 4940540) in 2003-2004 and 2005-2006 revealed that phosphorus levels were almost always below the detection limit of 0.02 mg/L, except during occasional periods of high flow from runoff events. This is likely further evidence of the influence of volcanic geology on phosphorus levels in the headwaters of Bowery Creek and Yankee Meadow Reservoir. Internal loading in the reservoir from the release of phosphates from lake sediments may also be occurring (Horne and Goldman 1994). If internal loading is a significant source of phosphorus, then reductions in other outside sources may have minimal impacts on reducing phosphorus levels in-lake.

Sampling in 2006-2007 showed full support for percent of the water column supporting the 4.0 mg/l DO criterion. However, indications of possible supersaturation in some months during the day could imply that DO levels decline at night when photosynthesis stops. Supersaturation as well as elevated pH levels, implies that there is excessive algae and/or macrophyte growth. Potentially supersaturated DO conditions for the 2006-2007 sample year occurred in May and July 2006 while pH levels over 9.0 occurred from May through September 2006. Water temperatures near the surface exceeded 20^{o}C in July 2006. During the presence of a thermocline in May 2006 and May 2007, there is a clear increase in DO levels and pH levels in and around the thermocline, which would indicate abundant algal growth within this zone from gentle mixing (Horne and Goldman 1994). Under natural lake conditions, the thermocline would likely remain through the summer until fall turnover; however, the annual release of water from the reservoir starting in late May to June and subsequent drop in water depth eliminates any clear thermal stratification. Highest depths tend to be in May from accumulation of snowmelt and before releases begin (typically around 10 meters deep), then drop to around 5 to 6 meters by August, and remaining at low levels until the following spring runoff. Sample years 2000, 2002, and 2004 showed levels dropped to as low as 2 to 3 meters by August or September.

Looking at total and total dissolved phosphorus readings during the 2006-2007 sample year, months with mostly non-detect readings (June 2006; September-November 2006; April-May 2007) corresponds with the months that chlorophyll-a readings place the reservoir in an oligotrophic state. Total and total dissolved phosphorus readings exceed the 0.025 mg/l indicator value most often in the bottom half of the lake. Anoxic conditions at the bottom of the reservoir in late winter to early spring could be an indication of internal loading via release of phosphorus from lake sediments (Horne and Goldman 1994), which would also correspond with the reservoir being mesotrophic (based on chlorophyll-a) during that time period. Other periods of increased detection of total and total dissolved phosphorus loosely fall within typical periods of higher runoff, such as the summer monsoonal thunderstorm season and spring snowmelt.

Researchers of the U. S. Geological Survey (Winter et al.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 Bowery 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 no evidence of man-made phosphorus sources in Bowery Creek, it is likely that the phosphorus entering the lake is mostly from natural sources of ground water.

7.0 Summary

The results of the water quality data and land management activities in the watershed indicate that DO criteria are fully supported and natural processes are causing exceedances of the water quality standard for pH in Yankee Meadow Reservoir. The primary sources of phosphorus loading into the Reservoir include internal loading from bottom sediments, and groundwater and native geology contributions to Bowery Creek.

Since anthropogenic activities have not caused the impairment, Yankee Meadows Reservoir is recommended to be placed in Category 4C of the State of Utah's 303d List as not impaired by a pollutant.

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