Wasatch-Cache National Forest Lakes Report
March 1, 2006

Executive Summary

Bridger, China, Lyman and Marsh Lakes were listed by the State of Utah as impaired water bodies due to low dissolved oxygen concentrations that did not meet State water quality standards. In partnership with Utah Division of Water Quality (UDWQ), the Wasatch-Cache National Forest (WCNF) collected data from these Lakes from August 2004 to August 2005 to provide recent detailed water quality information to support an analysis of its beneficial use impairment. Based on the information collected from the lakes and their surrounding watersheds it has been determined that the cause of impairment is natural and not caused by a pollutant and therefore these waters should be placed within Category 4C of the State of Utah's 303d List. This report is organized as listed below.

- Section 1.0: Description of each individual water body and its associated watershed.
- Section 2.0: Description of designated beneficial uses and relevant water quality standards for the parameters of concern.
- Section 3.0: Discussion of water quality targets and appropriate endpoints
- Section 4.0: Assessment of causes and sources of impairment.
- Section 5.0: Assessment of pollutant sources.
- Section 6.0: Technical analysis of water quality data in relationship to abiotic and biological processes.
- Section 7.0: Use Attainability Analysis.
- Section 8.0: Discussion of management options and practices.

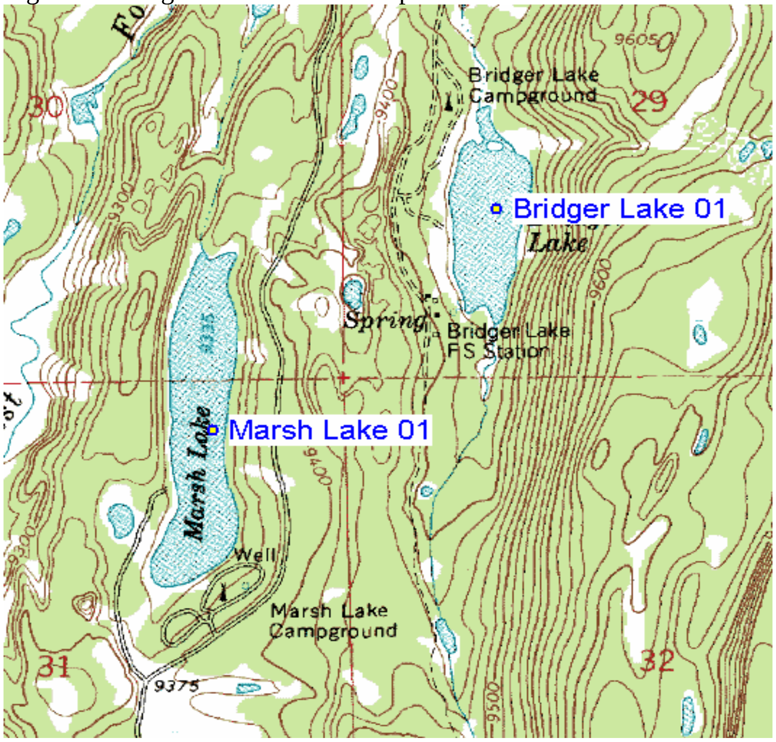
1.0 Introduction

All of the waterbodies evaluated in this study, Bridger, Lyman, Marsh and China Lakes, are located on the northern slope of the Uinta Mountains within the Wasatch-Cache National Forest.

Bridger Lake

Bridger Lake is a natural water body that lies in a glacially formed valley on the north slope of the Uinta Mountains at an elevation of 9,364 feet. The lake is 21 acres in size with a maximum depth of about five meters. It has one stream that flows into it and one that flows out of the lake. Estimates of water flows into Bridger Lake taken in 2005 range from 1.3 cubic feet per second (cfs) in June to 0.01 cfs in August. The watershed above the lake is rather small, about 950 acres in size. The watershed receives about 20 to 25 inches of precipitation annually with most in the form of snow that falls during the winter. Snowmelt is the principal source of surface flow into the lake during the short summer season. Groundwater is an important source of water that maintains a constant water depth in the lake throughout the year. The predominant vegetation type in the drainage is lodgepole pine in the uplands and sedges and willows along the small stream flowing into and out of the lake.

Figure 1. Bridger Lake Location Map



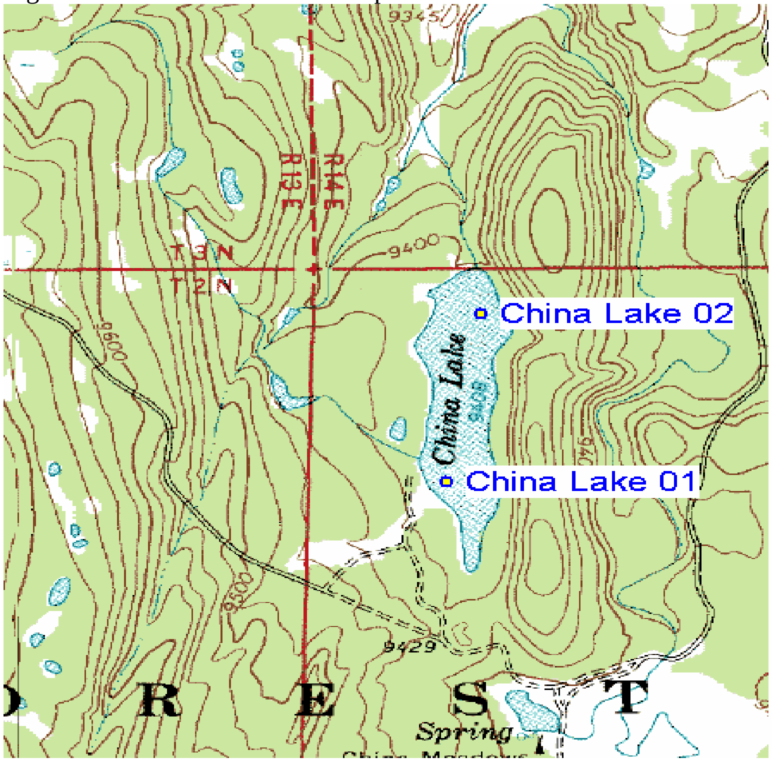
The ground cover in the watershed is in good to excellent condition. The shore surrounding Bridger Lake has dense vegetation in most areas and a well maintained hiking trail that goes around the lake. There is very little evidence of soil erosion around the lake and no sign of sediment reaching the lake. The stream flowing into and out of the lake is low gradient, meandering and has good ground cover along the banks. No livestock are allowed around the lake and a buck and pole fence surrounds the lake to keep livestock out.

The drainage surrounding the lake is entirely within federal ownership being part of the Wasatch-Cache National Forest. The lake is used for recreation and coldwater aquatic life. The water that passes through the lake is unregulated by man. A Forest Service campground with 32 units is located on the west side of the lake and an administrative site is located to the southwest of the lake. About ten years ago the campground was refurbished and now has two vault toilets that are in good condition and regraveled campground roads. An administrative site is located about 400 feet southwest of the lake and has two residences, several storage buildings, and a horse pasture located to the south of the lake between the administrative site and the inflow stream south the lake.

China Lake

China Lake is a natural water body with a man-made dam that was constructed in the 1950s and raised the elevation of the water in the lake above the natural height. It lies in a glacially formed valley on the north slope of the Uinta Mountains at an elevation of 9,498 feet. The lake is 31 acres in size with a maximum depth of about 14 meters, has one stream that flow into it from the west. This stream is a man-made water conveyance that is part canal and part natural stream course. Estimates of water flows of the stream into China Lake taken in 2005 range from 0.5 cubic feet per second (cfs) in June to 0.03 cfs in August. It captures water from several small drainages to the west of China Lake and routes the water through meadows and sections of earthen canal to the lake. The water in China Lake is used for irrigation and is drawn down about nine feet annually. The watershed above the lake is rather about 2,311 acres in size. The watershed receives about 20 to 25 inches of precipitation annually with most in the form of snow that falls during the winter. During the spring, runoff from snowmelt is the principal source of flow into the lake. For the remainder of the year, groundwater is the main source of water that maintains the water level in the lake. The predominant vegetation type in the drainage is lodgepole pine in the uplands that surround the lake.

Figure 2. China Lake Location Map



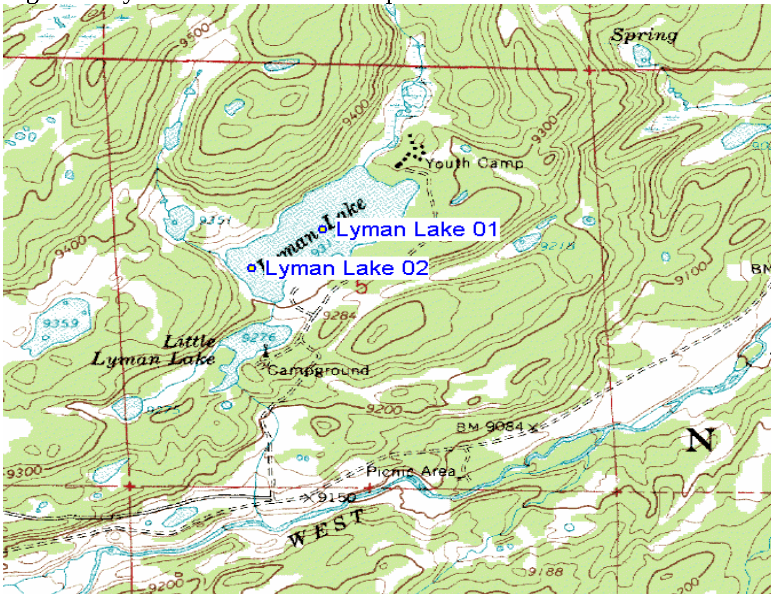
The ground cover in the watershed is in good to excellent condition. The shore surrounding China Lake has a lodgepole overstory and in most areas the ground is covered with duff, grasses, and forbs that protect the soil surface from erosion. There is very little evidence of soil erosion around the lake and no sign of sediment reaching the lake. No livestock are allowed around the lake.

The drainage surrounding the lake is in entirely within federal ownership being part of the Wasatch-Cache National Forest. The lake is used for recreation and coldwater aquatic life. Water in the lake is regulated by man and is released for irrigation. No man-made structures or facilities are located around the lake or within the watershed draining into the lake with the exception of a dam and outlet works and a canal that is used to route water into the lake from the west. A hiking trail provides access to the lake from the south.

Lyman Lake

Lyman Lake is a natural water body with a small man-made dam that was constructed in the 1950s and raised the elevation of the water in the lake above the natural height. The dam is about six feet in height and was built to provide a deeper and larger lake for irrigation. It lies in a glacially formed depression on the north slope of the Uinta Mountains at an elevation of 9,311 feet. The lake is 27 acres in size with a maximum depth of about seven meters, has two streams that flow into it from the west and a small stream that flows out of it to the southwest. Estimates of water flows of the larger stream that flows into Lyman Lake taken in 2005 range from 0.4 cubic feet per second (cfs) in June to 0.04 cfs in August. The watershed above the lake is about 386 acres in size. The watershed receives about 20 to 25 inches of precipitation annually with most in the form of snow that falls during the winter. During the spring, runoff from snowmelt is the principal source of flow into the lake. For the remainder of the year, groundwater is the main source of water that maintains the water level in the lake. The predominant vegetation type in the drainage is lodgepole pine in the uplands that surround the lake. The streams that flow into and out of the lake have dense sedge and willow riparian areas and are in very good condition.

Figure 3. Lyman Lake Location Map



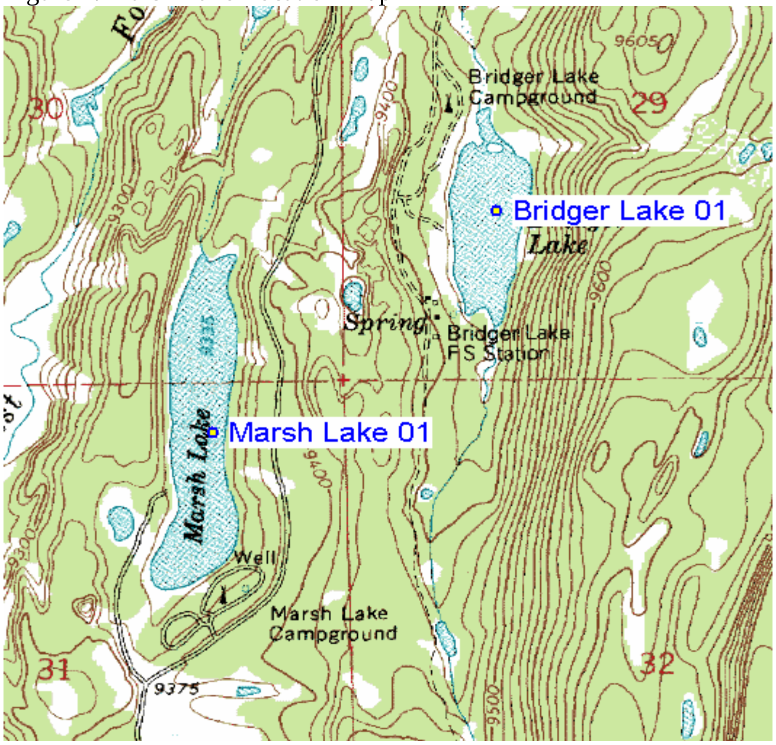
The ground cover in the watershed is in good to excellent condition. The shore surrounding Lyman Lake has a lodgepole overstory and in most areas the ground is covered with duff, grasses, and forbs that protect the soil surface from erosion. There is very little evidence of soil erosion around the lake and no sign of sediment reaching the lake. No livestock are allowed around the lake.

The drainage surrounding the lake is entirely within federal ownership being part of the Wasatch-Cache National Forest. The lake is used for recreation and coldwater aquatic life. Water in the lake has been raised a few feet by construction of a small dam for irrigation purposes. The Layton Stake Youth Camp is located on the north side of the lake and the facilities consist of several small cabins, a central meeting/dining building, one vault toilet and flush toilets and septic system. A Forest Service campground is located on the southwest side of the lake that consists of 10 units and a vault toilet that was installed 10 years ago. The campground is downstream of Lyman Lake and is not within the area draining into the lake. A gravel road that is located on the east side of the lake provides access to the Forest Service campground and the Layton Stake Youth Camp and some dispersed camping occurs between the road and the lake. A small hiking trail is located about twenty feet from the shore of the lake.

Marsh Lake

Marsh Lake is a natural water body that lies in a glacially formed valley on the north slope of the Uinta Mountains at an elevation of 9,335 feet. The lake is 38 acres in size with a maximum depth of about 10.5 meters, has no streams flowing into or out of it. The watershed above the lake is rather small, about 166 acres in size. The watershed receives about 20 to 25 inches of precipitation annually with most in the form of snow that falls during the winter. Goundwater from snowmelt is the principal source of flow into the lake. The predominant vegetation type in the drainage is lodgepole pine in the uplands that surround the lake.

Figure 4. Marsh Lake Location Map



The ground cover in the watershed is in good to excellent condition. The shore surrounding Marsh Lake has a lodgepole overstory and in most areas the ground is covered with duff, grasses, and forbs that protect the soil surface from erosion. There is very little evidence of soil erosion around the lake and no sign of sediment reaching the lake. No livestock are allowed around the lake.

The drainage surrounding the lake is in entirely within federal ownership being part of the Wasatch-Cache National Forest. The lake is used for recreation and coldwater aquatic life. The water in the lake is unregulated by man. East Marsh Lake and West Marsh Lake campgrounds are located on the east and west sides of the lake and contain 38 campground units, four two-hole vault toilets, and gravel roads. The campground is in very good condition because about two years ago, new toilets were installed, campsites were refurbished, and new gravel was placed on the roads that access the campsites.

2.0. Water Quality Standards

The State of Utah has categorized all the waters within the Wasatch-Cache National Forest as High Quality Waters, Class 1 within the Antidegradation Policy (R317-2; Standards of Quality for Waters of the State) indicating that the existing water quality is better than the established standards for the designated beneficial uses and that water quality is required by state regulation to be maintained at this level. The designated beneficial uses of all waters within the Forest 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). The relevant water quality parameter associated with the lakes' designation as impaired for their Class 3A beneficial use is dissolved oxygen. The following Table 1 shows Utah's dissolved oxygen criteria for class 3A waters.

Table 1. 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 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

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

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 25-50% 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, State of 2005).

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 that 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.

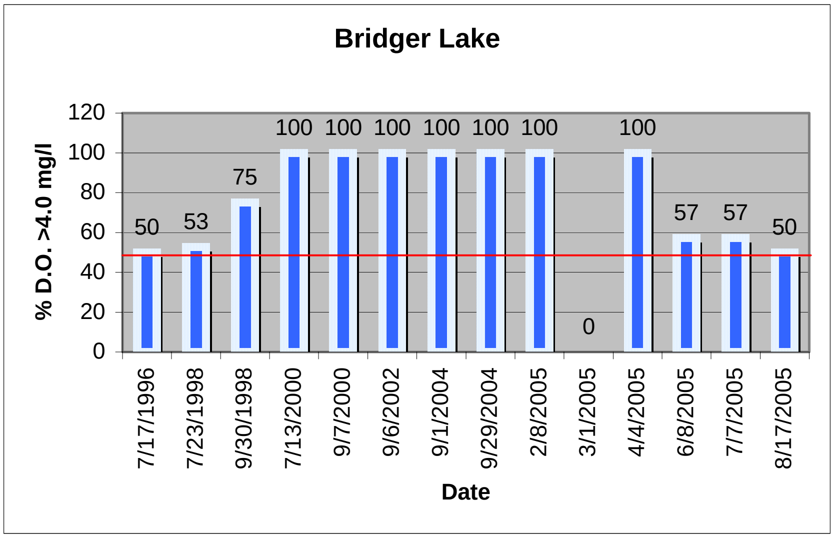
Table 2 presents the 303(d) listings for Bridger, China, Lyman, and Marsh Lakes.

Table 2. Utah 2004 303(d) listings for Bridger, China, Lyman and Marsh Lakes.

Waterbody	Waterbody Size	Beneficial Use Impaired	Pollutant or Stressor
Bridger Lake	21 acres	3A Cold Water Species of Game Fish	Dissolved Oxygen
China Lake	31 acres	3A Cold Water Species of Game Fish	Dissolved Oxygen
Lyman Lake	27 acres	3A Cold Water Species of Game Fish	Dissolved Oxygen
Marsh Lake	38 acres	3A Cold Water Species of Game Fish	Dissolved Oxygen

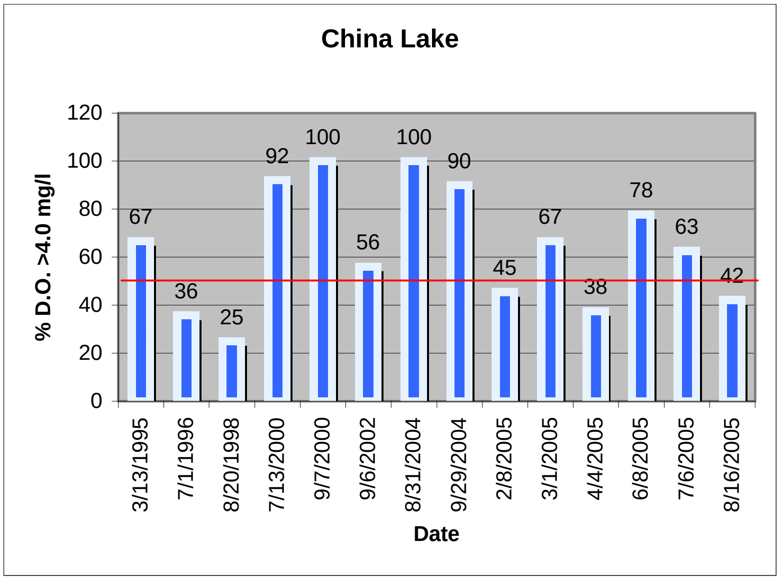
The percentage of the total water column above the 4 mg/L is depicted in the following Figures 5-8 for each individual lake. For Bridger Lake (Figure 5) dissolved oxygen impairment occurs only occurs during the winter season when the water column is not greater than 4 mg/l over 50 percent of the water column.

Figure 5. Percent of Water Column above 4 mg/L Dissolved Oxygen



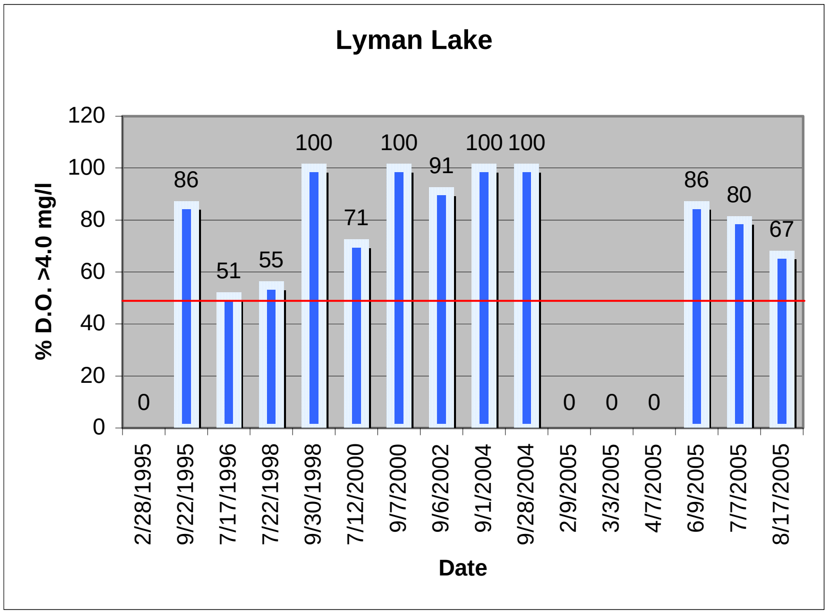
For China Lake (Figure 6), nine of 14 sample rounds from 1995 to 2005 met the 50% of the water column supporting 4 mg/l dissolved oxygen criteria. During the 2004-2005 sampling rounds, 5 of 8 samples rounds met the 50% of the water column supporting 4 mg/l dissolved oxygen criteria. The months of February, April, and August 2005 were below the 50% of the water column supporting 4 mg/l dissolved oxygen criteria. Dissolved oxygen changes with depth throughout the year.

Figure 6. Percent of Water Column above 4 mg/L Dissolved Oxygen



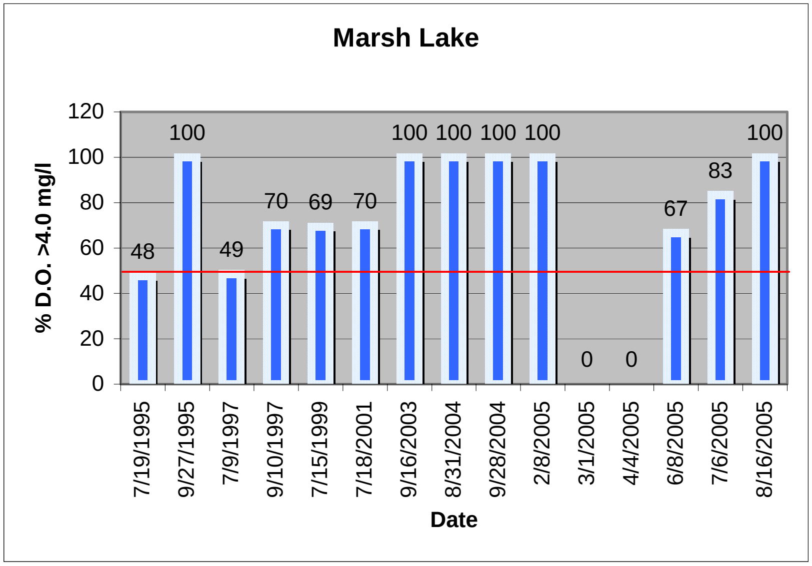
For Lyman Lake (Figure 7), based on measurements from 1995 to 2005, 12 of 16 sample rounds met the 50% of the water column supporting 4 mg/l dissolved oxygen criteria. All of the four winter sample rounds taken in February 1995 and February, March, and April 2005 had dissolved oxygen concentrations below the 4 mg/l dissolved oxygen criteria from the surface to the bottom of the lake.

Figure 7. Percent of Water Column above 4 mg/L Dissolved Oxygen



Marsh Lake (Figure 8), exhibits a similar pattern where 11 of 15 sample rounds met the 50% of the water column supporting the 4 mg/l dissolved oxygen criteria. The two winter sample rounds taken in March and April 2005 had dissolved oxygen concentrations below the 4 mg/l dissolved oxygen criteria from the surface to the bottom of the lake.

Figure 8. Percent of Water Column above 4 mg/L Dissolved Oxygen



3.0 Water Quality Targets/Endpoints

This section discusses whether the impairments are naturally occurring and if not, what quantifiable targets or endpoints will achieve water quality standards.

Pollution from point sources and nonpoint sources can enter a lake and cause water quality problems. The USEPA (Olem and Flock 1990, 94) states that point source wastewater from industrial, municipal, and household sources can be high in organic matter, bacteria, and nutrients. Discharge of wastewater into a lake can be assessed by looking for indicators of pollution such as algae blooms or turbid water. Non-point sources of pollution can also contaminate lakes through runoff and groundwater. Runoff can carry sediment and fertilizers from roads, lawns, 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.

Point source and nonpoint source pollution does not appear to be occurring in Bridger, China, Lyman and Marsh Lakes. The watersheds that drain into these lakes do not have point sources of pollution because there are no industrial, municipal, or household discrete points of wastewater discharges. Runoff carrying sediment is the only nonpoint sources of pollution that could cause pollution to enter the lakes because human waste is contained in vault toilets that are functioning and maintained properly. Land conditions around the lakes indicate that runoff is controlled and sediment above naturally occurring amounts is not entering the lakes. A review of possible sediment sources along the shorelines surrounding the lakes was conducted during field visits in the summer of 2004 and no sediment deposition was noted.

The USEPA (USEPA 1990, 41) states that the delineation of man-made versus natural causes of problems can be enhanced by reviewing water quality conditions of other lakes in the region and if similar problems occur in relatively undisturbed watersheds then the specific lake's problem could be from natural causes. This appears to be the case with Bridger, China, Lyman and Marsh Lakes which are all located in relatively undisturbed watersheds of the same region, geological type, weather patterns, aspect, and water regime. All of these lakes have dissolved oxygen impairment that occur during the same season, surface water flow from streams into the lakes are very low or non-existent, nutrient values of the inflow and lakes are very low or not-detectable. This indicates that the impairments are naturally occurring and not caused by activities of man.

Bridger, China, Lyman and Marsh Lakes appear to be acting under natural processes. The trophic state is what is expected from lakes that have low nutrient inputs in a coniferous forest environment. As shown in Tables 3-6 in Section 5, man-made inputs of phosphorus and nitrogen are not detected and it appears that dissolved oxygen is used up in the winter as a result of low photosynthesis due to low light conditions because of ice and snow covering the entire lake surface, from macrophyte respiration, and bacteria respiration that uses up oxygen during the decay of dead plants and animals.

4.0 Source Assessment

Land management activities do not appear to be contributing to dissolved oxygen impairment that occurs during the winter season. Ground cover, which is an indicator of how well soil is protected from erosion, is good to excellent in each lake's watershed, there is very little evidence of soil erosion around the lakes, and nutrients are not detected in samples taken from the tributary streams. As discussed in Section 6, several projects to aerate water in nearby lakes have not been successful. No management actions are recommended at this time because the lakes are functioning under natural processes. Exceedance of the dissolved oxygen criteria occurs during the winter when snow depths are high and respiration from macrophytes and bacterial decay naturally consume the oxygen in the shallow lakes.

5.0 Significant Sources

In order to identify sources of pollution, maps were reviewed to determine where surface water drains into Bridger, China, Lyman and Marsh Lakes, what and where man-made activities occur within the watershed, and field visits during the summer of 2004 looked at land conditions such as the amount as ground cover, sediment deposition, rills and gullies, and other indicators of erosion and sedimentation. As result of these reviews, no significant sources of pollution were identified.

Bridger Lake

Nutrient loads entering and within Bridger Lake are very low, other than bottom samples, as seen in Tables 3 and 4. Total phosphorus as P and dissolved nitrate and nitrite values for Bridger Lake inflow and outflow streams were below the detection limit for all four samples collected between September 2004 and August 2005. The ground cover in the watershed that drains into Bridger Lake is in good to excellent condition. The shore surrounding Bridger Lake has dense vegetation in most areas and a hiking trail that goes around the lake is well maintained. There is very little evidence of soil erosion around the lake and no sign of sediment reaching the lake. The low gradient meandering stream flowing into and out of the lake has good ground cover along the banks with only a few areas where horses water drink from the inflow stream. No livestock are allowed around the lake and a buck and pole fence surrounds the lake to keep livestock out. About ten years ago the campground located west of the lake was refurbished and now has two vault toilets that are in good condition and re-graveled campground roads.

Table 3. Bridger Lake - Nutrients by depth level in lake.

	Dissolved Total Phosphorus as P (mg/l)					Total Phosphorus as P (mg/l)					D-NO2+NO3, N (mg/l)				
Date	**21 ***	**23**	**25**	**27**	**29**	**21**	**23**	**25**	**27**	**29**	**21**	**23**	**25**	**27**	
6/24/1981						0.030									
6/17/1992	ND				0.022	ND				0.030	ND				0
8/11/1992	ND				0.015	0.036				0.054	ND				
7/27/1994	0.015				ND	0.024				0.027	ND				
9/8/1994	0.025	0.902			0.213	0.024	0.024			0.031	ND	0.027			0
3/21/1995										ND					
7/19/1995	ND	ND		0.01	0.01	ND	ND		0.010	0.490	ND	ND		ND	
9/27/1995	0.01					0.030					0.04				
7/17/1996	ND				ND	0.010				0.010	ND				
9/11/1996	0.01				0.02	0.010				0.020	ND				
7/23/1998	ND				ND	ND				0.791	ND				
9/30/1998	0.02				ND	ND				0.039	ND				
7/13/2000	ND				0.028	ND				ND	0.1				
9/7/2000	ND				ND	ND				ND	ND				
10/3/2001		0.02					0.027					ND			
6/26/2002	ND				ND	ND				ND	ND				
9/6/2002	ND				ND	0.027				0.028	ND				
9/1/2004	ND				ND	ND				ND	ND				
9/29/2004	ND				ND	ND				ND	ND				
2/8/2005	ND				0.042	ND				0.059	ND				
3/1/2005	ND				0.092	ND				0.136	ND				
4/4/2005	ND				ND	ND				0.028	ND				
6/8/2005	ND				ND	0.021				0.024	ND				
7/7/2005	ND				ND	ND				0.038	ND				
8/17/2005	ND				ND	ND				0.022	0.25				

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).

* 21 indicates surface sample, 23 above thermocline when present, 25 midpoint of water column when no thermocline is presnet,
27 below thermocline when present, and 29 indicates a bottom sample

Table 4. Selected Data for unnamed streams above and below Bridger Lake.

Date	D-Total Phosphorus (mg/l)	Total Phosphorus (mg/l)	D-NO2+NO3, N (mg/l)	Location
9/1/2004	<0.02	<0.02	<0.1	Above
2/8/2005	No samples collected above or below			
3/1/2005	No samples collected above or below			
4/4/2005	No samples collected above or below			
6/8/2005	<0.02	<0.02	<0.1	Above
6/8/2005	<0.02	<0.02	<0.1	Below
7/7/2005	<0.02	<0.02	<0.1	Above
7/7/2005	<0.02	<0.02	<0.1	Below
8/17/2005	<0.02	<0.02	<0.1	Above
8/17/2005	<0.02	<0.02	<0.1	Below

China Lake

As shown in Tables 5 and 6, nutrient loads within and entering China Lake are very low, other than bottom samples. For the China Lake inflow stream, total phosphorus as P was below the detection limit or just above the detection limit for all four samples collected between August 2004 and August 2005. Dissolved nitrate and nitrite values were below the detection limit for all four samples collected between August 2004 and August 2005. The ground cover in the watershed is in good to excellent condition. The shore surrounding China Lake has a lodgepole overstory and in most areas the ground is covered with duff, grasses, and forbs that protect the soil surface from erosion. There is very little evidence of soil erosion around the lake and no sign of sediment reaching the lake. No livestock are allowed around the lake. Although water in the lake is regulated by man and is released for irrigation, and a dam, outlet works, and a canal is used to route water, no pollution such as soil erosion or sedimentation has been seen entering the lake. The hiking trail that provides access to the lake from the south is not contributing sediment to China Lake.

Table 5. China Lake - Nutrients by depth level in lake.

	Dissolved Total Phosphorus as P (mg/l)					Total Phosphorus as P (mg/l)					D-NO2+NO3, N (mg/l)				
Date	**21***	**23**	**25**	**27**	**29**	**21**	**23**	**25**	**27**	**29**	**21**	**23**	**25**	**27**	
6/24/1981						0.030									
6/17/1992	0.016	ND		ND	0.014	0.042	ND		ND	0.014	ND	ND		ND	
8/11/1992	ND	ND		0.014	0.019	0.017	0.049		0.021	0.072	ND	ND		ND	
7/27/1994		0.010			0.022	0.013	0.012		0.015	0.029	ND	ND		ND	
9/8/1994	0.010	0.010		0.010	0.019	ND	ND		ND	0.028	ND	ND		ND	
3/14/1995										ND					0.
7/17/1996	0.010	ND		0.010	0.010	0.010	ND		0.01	0.020	ND	ND		0.070	0.
9/11/1996	0.010	ND		0.010	0.010	ND	ND		ND	0.030	ND	ND		0.030	0.
8/20/1998	ND	0.031		ND	0.148	0.024	0.029		0.035	0.191	ND	ND		ND	
9/30/1998	ND				0.060	ND				0.061	ND				
7/13/2000	0.024	0.027		0.021	0.045	ND	ND		ND	0.033	0.100	0.100		0.100	0.
9/7/2000	ND				ND	ND				ND	ND				0.
6/26/2002	ND				ND	ND				ND	ND				
9/6/2002	ND	ND		0.036	0.065	0.020	ND		0.021	0.100	0.550	0.120		0.160	
8/31/2004	ND				ND	ND	0.021		ND	ND	ND	ND		ND	
9/29/2004	ND		ND		0.046	ND		ND		0.149	ND		ND		
2/8/2005	ND		ND		0.033	ND		ND		0.046	ND		ND		
3/1/2005	ND		ND		0.027	ND		ND		0.034	ND		0.100		
4/4/2005	ND		ND		0.027	ND		ND		0.031	0.100		0.160		0.
6/8/2005	ND	ND		ND	0.027	ND	ND		0.025	0.049	ND	ND		ND	
7/6/2005	ND	ND		ND	0.021	ND	ND		0.021	0.043	ND	ND		ND	
8/16/2005	ND	ND		ND	0.086	ND	ND		0.028	0.129	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).

* 21 indicates surface sample, 23 above thermocline when present, 25 midpoint of water column when no thermocline is presnet,
27 below thermocline when present, and 29 indicates a bottom sample

Table 6. Selected Data for unnamed streams above China Lake.

Date	**D-Total Phosphorus (mg/l)**	**Total Phosphorus (mg/l)**	**D-NO2+NO3, N (mg/l)**
8/31/2004	0.02	0.03	<0.1
2/8/2005	No samples collected above or below		
3/1/2005	No samples collected above or below		
4/4/2005	No samples collected above or below		
6/8/2005	ND	ND	<0.1
7/6/2005	ND	0.03	<0.1
8/17/2005	ND	ND	<0.1

Lyman Lake

As shown in Tables 7 and 8, nutrient loads within and entering Lyman Lake are very low. Total phosphorus as P and dissolved nitrate and nitrite values for Lyman Lake inflow and outflow streams were below the detection limit for samples collected between June and August 2005 with the exception of the stream flowing into Lyman Lake in July and August. The dissolved nitrate and nitrite values for these months were 0.1 mg/l which is just above the detection limit. The ground cover in the watershed is in good to excellent condition. The shore surrounding Lyman Lake has a lodgepole overstory and in most areas the ground is covered with duff, grasses, and forbs that protect the soil surface from erosion. There is very little evidence of soil erosion around the lake and no sign of sediment reaching the lake. No livestock are allowed around the lake. Although the water in the lake has been raised a few feet for irrigation purposes, there is no appearance that water is released for irrigation purposes as indicated by the lack of a “bathtub ring” along the shore of the lake.

Table 7. Lyman Lake - Nutrients by depth level in lake.

	Dissolved Total Phosphorus as P (mg/l)					Total Phosphorus as P (mg/l)					D-NO2+NO3, N (mg/l)				
Date	**21***	**23**	**25**	**27**	**29**	**21**	**23**	**25**	**27**	**29**	**21**	**23**	**25**	**27**	
6/24/1981															
6/17/1992	ND				ND	ND				0.017	ND				
8/11/1992	0.027		ND		0.017	0.034		0.020		0.023	0.029		ND		
7/27/1994	ND				ND	ND				0.018	ND				
9/7/1994	ND	ND		ND	ND	ND	ND		0.014	ND	ND	ND		0.113	
3/21/1995											ND	ND		ND	
7/19/1995	ND	ND		0.010	0.040	ND	ND		ND	0.010	ND	ND		ND	
9/27/1995	ND		ND		ND	0.020		0.010		0.010	0.020		0.020		58.
7/17/1996	ND	ND		ND	0.010	ND	ND		0.010	0.020	ND	ND		ND	
9/11/1996	ND	ND		ND	ND	ND	ND		ND	ND	ND	ND		ND	
7/22/1998	ND	ND		ND	ND	ND	ND		ND	ND	ND	ND		ND	
9/30/1998	ND	ND		ND	ND	ND	ND		ND	ND	ND	ND		ND	
7/12/2000	ND	0.020			ND	ND	ND			ND	0.100	0.100			0.
9/7/2000	ND				ND	ND				ND	ND				0.
10/3/2001															
6/26/2002	ND				ND	ND				ND	0.100				
9/6/2002	0.037				0.038	ND				ND	ND				0.
8/31/2004	ND				ND	ND				ND	ND				
9/28/2004	ND				ND	ND				ND	ND				
2/9/2005	ND		ND		ND	ND		ND		ND	ND		ND		
3/3/2005	ND		ND		ND	ND		ND		ND	ND		ND		
4/7/2005	ND		ND		ND	0.081		ND		0.020	ND		ND		
6/9/2005	ND			ND	ND	ND			ND	ND	ND			ND	
7/7/2005	ND			ND	ND	ND			ND	ND	0.550		ND		0.
8/17/2005	ND	ND		ND	ND	ND	ND		ND	0.020	0.330	0.170		0.340	0.

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).

* 21 indicates surface sample, 23 above thermocline when present, 25 midpoint of water column when no thermocline is presnet,
27 below thermocline when present, and 29 indicates a bottom sample

Table 8. Selected Data for unnamed streams above and below Lyman Lake.

Date	**D-Total Phosphorus (mg/l)**	**Total Phosphorus (mg/l)**	**D-NO2+NO3, N (mg/l)**	**Location**
9/1/2004	No samples collected above or below			
2/8/2005	No samples collected above or below			
3/1/2005	No samples collected above or below			
4/4/2005	No samples collected above or below			
6/9/2005	ND	ND	<0.1	Above
6/9/2005	ND	ND	<0.1	Below
7/7/2005	ND	ND	0.10	Above
7/7/2005	ND	ND	<0.1	Below
8/17/2005	ND	ND	0.10	Above
8/17/2005	ND	ND	<0.1	Below

Marsh Lake

As shown in Table 9, from 1999 to 2005 most values of dissolved and total phosphorus as P were not detected and those that were detected were from the bottom samples with the exception of one that was in the middle level sample. Dissolved nitrate and nitrite values for Marsh Lake were mostly below the detection limit for all four samples collected between September 2004 and August 2005 and those that were above the detection limit were well below the State standard. This indicates that the source of nutrients is from the lake bottom and not from surface sources. The ground cover in the watershed that drains into Marsh Lake is in good to excellent condition. The shore surrounding Marsh Lake has dense vegetation in most areas and a areas around the lake that is used for fishing has good ground cover. There is very little evidence of soil erosion around the lake and no sign of sediment reaching the lake. No livestock are allowed around the lake. The water in the lake is unregulated by man. East Marsh Lake and West Marsh Lake campgrounds are located on the east and west sides of the lake and contain 38 campground units, four two-hole vault toilets, and gravel roads. The campground is in very good condition and about two years ago, new toilets were installed, campsites were refurbished, and new gravel was placed on the roads that access the campsites.

Table 9. Marsh Lake - Nutrients by depth level in lake.

	Dissolved Total Phosphorus as P (mg/l)					Total Phosphorus as P (mg/l)					D-NO2+NO3, N (mg/l)				
Date	**21***	**23**	**25**	**27**	**29**	**21**	**23**	**25**	**27**	**29**	**21**	**23**	**25**	**27**	**29**
6/24/1981						0.030				0.030					
6/27/1989						ND	ND		0.017	0.031					
8/29/1989						ND	ND		ND	ND					
4/10/1990										0.097					
6/18/1991	ND	ND		0.023	0.015	ND	ND		0.017	0.011	ND	ND		0.013	0.010
9/4/1991				0.010		ND	ND		ND	ND	ND	ND		ND	ND
7/7/1993	0.014	0.012		0.016	0.023	ND	0.020		0.022	0.057	ND	ND		ND	ND
9/16/1993	ND	ND		ND	ND	ND	ND		ND	0.031	ND	ND		ND	0.033
7/27/1994	ND	ND		ND	ND	ND	ND		0.011	0.024	ND	ND		ND	ND
3/14/1995										ND					ND
7/19/1995	ND	ND		ND	ND	ND	ND		0.010	ND	ND	0.020		0.320	ND
9/27/1995	ND	0.010		ND	ND	ND	ND		ND	0.010	ND	ND		ND	0.020
7/9/1997	0.026	0.067			0.026						ND	ND			ND
9/10/1997	0.052										ND	ND			ND
7/15/1999	ND	ND		ND	ND	0.024	0.023		0.021	0.021	ND	ND		ND	ND
9/28/1999	ND	ND		ND	ND	0.020				ND	ND				ND
7/18/2001	ND	ND		ND	ND	ND	ND		ND	ND	ND	ND		ND	ND
10/2/2001		ND		ND			ND		ND	ND		ND		0.140	0.200
7/8/2003	ND	ND		ND	0.026	ND	ND		ND	0.022	ND	ND		ND	ND
9/16/2003	ND	ND		ND	ND	ND	ND		ND	ND	ND	ND		ND	ND
8/31/2004	ND		ND		ND	ND				ND	ND				ND
9/28/2004	ND		ND		ND	ND				ND	ND				ND
2/8/2005	ND		ND		ND	ND		ND		0.046	ND		ND		ND
3/1/2005	ND		ND		ND	ND		0.036		0.056	ND		ND		ND
4/4/2005	ND		ND		ND	ND		ND		0.052	ND		ND		ND
6/8/2005	ND	ND		ND	ND	ND	ND		ND	0.024	ND	ND		ND	ND
7/6/2005	ND	ND		ND	ND	ND	ND		ND	ND	ND	0.110		0.430	ND
8/16/2005	ND		ND		ND	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).
* 21 indicates surface sample, 23 above thermocline when present, 25 midpoint of water column when no thermocline is presnet,
27 below thermocline when present, and 29 indicates a bottom sample

6.0 Technical Analysis

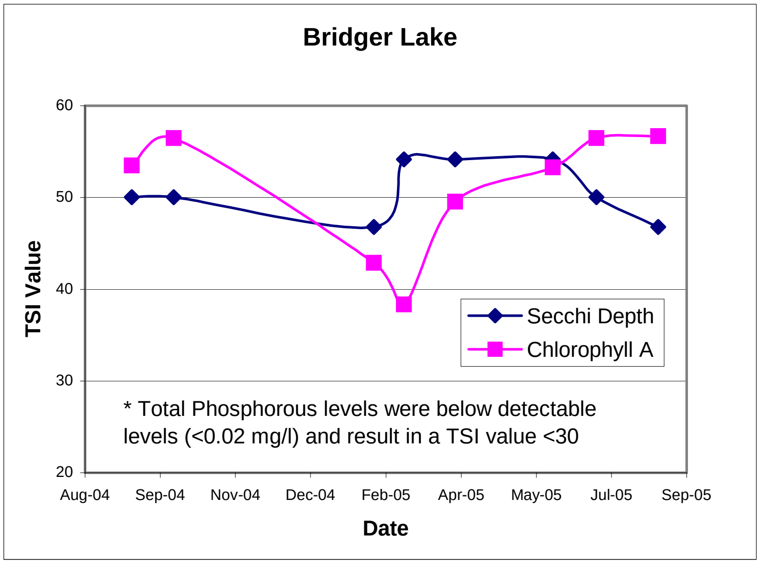
This section contains a description of water quality data conditions of Bridger, China, Lyman and Marsh Lakes and at the end, a discussion containing a summary by Bronmark and Hansson (2005) of abiotic and biological processes that occur in lakes and ponds and a comparison of these concepts with the water quality conditions of the lakes considered in this study.

Bridger Lake

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 states to indicate 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, or 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 2005).

Based on chlorophyll-a sampling between 2004 and 2005, the trophic states based on chlorophyll samples in Bridger Lake varied from eutrophic (TSI (Chl) of 50 to 60) from May through September to mesotrophic and high end of oligotrophic (TSI (Chl) from 38 to 50) from February to April (Figure 9). The clarity of the water as indicated by the secchi depth is the reverse of this pattern where the water clarity is generally higher during the summer months than during the winter months. The trophic state using secchi depth gave values that were between upper mesotrophic and eutrophic. Phosphorus could not be used for comparison because all of the samples were below the detection limit.

Figure 9. Bridger Lake Trophic State Indices



* Total Phosphorous levels were below detectable levels (<0.02 mg/l) and result in a TSI value <30

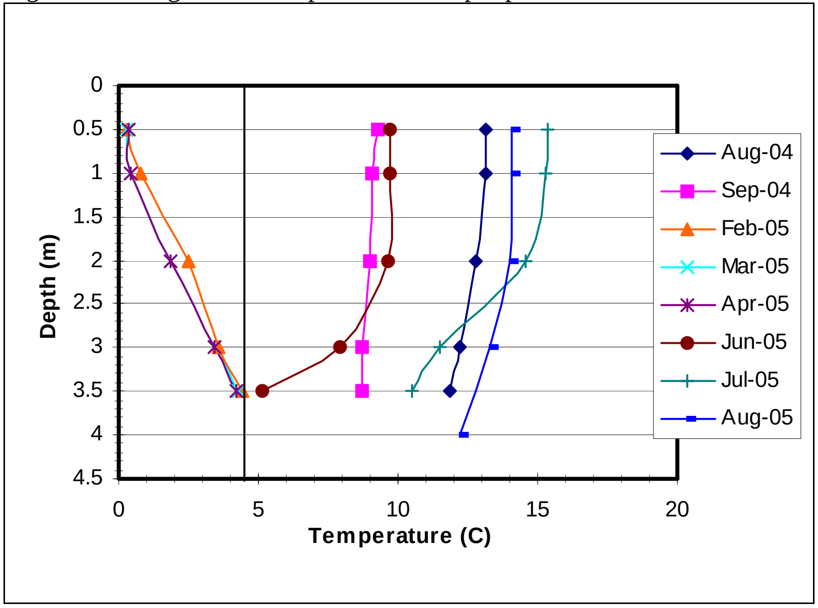
Carlson presents characteristics of north temperate lakes based on the trophic state and says that when lakes become mesotrophic, the hypolimnia of shallow lakes is likely to become anoxic that may result in a loss of salmonids and when lakes are eutrophic, the hypolimnia is anoxic and macrophyte problems are possible (Kent State 2005). Bridger Lake has these characteristics throughout most of the year when the lake is mesotrophic and eutrophic.

A reason that the algae biomass is in a eutrophic state during the warmer periods of the year is that those organisms that feed on the phytoplankton, such as zooplankton, may be absent or in low populations in the lake water. Since phosphorus and nitrogen concentrations are very limited in the lake and tributary flows, phytoplankton would increase during the warmer periods of the year due to the lack of herbivory by upper levels of the food chain.

Lake Morphology – Bridger Lake is somewhat rectangular in shape and is about 700 feet wide, 2000 feet long, and has a mean depth of 13 feet.

Temperature – The temperature of Bridger Lake from 2004 to 2005 ranges in mid-winter and mid-summer from 0 to 15.4ºC at the surface and from 4 to 13ºC near the bottom at a depth of 3.5 meters (Figure 10). The winter temperature profile is 0ºC at the ice surface and warms up linearly to 4ºC at a depth of 3.5 meters. Stratification of water temperatures occurs only in June and July when a thermocline develops at the 2-meter depth. In June, the temperature/depth profiles have temperatures of 9.7ºC at 2 meters, 7.9ºC at 3 meters and 5.1ºC at 3.5 meters. In July, the temperatures change similar to June except the temperatures are about five degrees warmer. In August and September, there is very little difference between the surface and deeper waters of the temperature profile indicating mixing of the water in the lake during autumn.

Figure 10. Bridger Lake temperature vs. depth profiles



Light (secchi depth, chlorophyll concentration) **–** The secchi depth in Bridger Lake from 2004 to 2005 ranged from 1.5 to 2.5 meters and the 1.5 m depths were recorded in March, April and June 2005. During the winter of 2004-2005, ice was about two-feet thick and snow was about one-foot deep and lay upon the entire surface of the ice.

Catchment Area (size of catchment, type of geology) **–** The watershed draining into Bridger Lake is about 950 acres in size and the lake was formed in a depression left from glaciers possibly about 13,000 years ago. The predominant vegetation type in the drainage is lodgepole pine in the uplands and sedges and willows along the small stream flowing into and out of the lake. 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 (Bronmark and Hansson 2005).

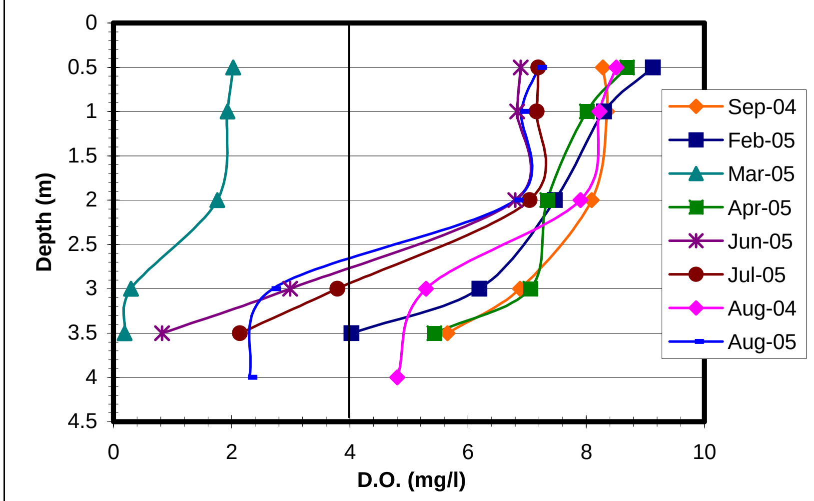
pH **–** The pH values for water samples collected in Bridger Lake from 2004 to 2005 were between 6.4 and 8.0. The pH trend is water becomes slightly acidic in the late winter and then becomes slightly alkaline in summer. The pH of the inflow water ranged from 6.9 to 8.0 and the outflow water ranged from 6.9 to 7.0. The pH of Bridger Lake is tends to be slightly alkaline and is typical of most lakes of the earth. According to Bronmark and Hansson (2005), the majority of lakes on earth have a pH between 6 and 9.

Nutrients **–** In the surface samples collected in Bridger Lake in 2004 and 2005, total phosphorus as P was below the detection limit for all samples except for samples in June which had a value of .021 mg/l. In the bottom samples, total phosphorus as P was above the pollution indicator criteria of 0.025 mg/l in four of eight sample rounds that occurred during February, March, April, and July 2005 and had a range of values between 0.028 and 0.136 mg/l. Dissolved nitrate + nitrite values for water samples collected in Bridger Lake in 2004 and 2005 were below the detection limit except for August 2005 of which the values were 0.25 mg/l at the surface and 0.38 mg/l at the bottom. Total phosphorus as P and dissolved nitrate and nitrite values for Bridger Lake inflow and outflow streams were below the detection limit for all four samples collected between September 2004 and August 2005.

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. The phosphorus and total nitrogen concentration of Bridger Lake is typical of most lakes unaffected by man since almost all samples of total phosphorus as P taken throughout that water column are below 0.1 mg/l and almost all dissolved nitrate + nitrite concentrations are below detection and those that have been detected have a highest value of 0.5 mg/l taken as a bottom sample.

Oxygen **–** From measurements collected 2004 and 2005, the dissolved oxygen profile shows stratification occurring throughout the year (Figure 11). In March 2005, the entire dissolved oxygen profile was anoxic with dissolved oxygen concentration of 2 mg/l from the surface to two feet deep and almost all oxygen used up at the bottom. It appears that in the middle of the winter, dissolved oxygen is almost all used up through the entire profile when ice and snow is on the lake surface. The other ice-covered months of February and April had oxygen profiles that were all above the standard of 4 mg/l.

Figure 11. Bridger Lake dissolved oxygen vs. depth profiles



The amount of dissolved oxygen changes seasonally, particularly at the surface where dissolved oxygen values were between 6.5 and 9 mg/l to a depth of two feet for all measurements taken except in March as noted previously. At depths below two feet, the dissolved oxygen becomes less the deeper it is in the lake, ranging from 0.8 to 5.7 mg/l at the bottom, and the lowest values at the bottom occurring from June through August of 2005, aside from the March readings.

Macrophytes – Macrophytes grow on most of the lake bottom of Bridger Lake. On the west side of the lake, emergent macrophytes grow to 50 feet from the shoreline. On the north and south ends of the lake, emergent macrophytes grow about 150 feet from the shoreline in shallow areas where stream water flows in and out of the lake. The east side of the lake has very little emergent macrophyte growth.

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% the amount of light at the surface is about 12 meters (Bronmark and Hansson 2005). In Bridger Lake the maximum depth of macrophyte growth would be to the bottom of the lake, 3.5 meters, based on the relationship between secchi depth and maximum depth of growth of angiosperms by Chambers and Kaiff (1985) as shown in Bronmark and Hansson (2005). The relationship indicates that at a secchi depth of 3.5 meters the maximum depth of angiosperm growth would be 1.5 to 5 meters. Plants can overcome the depth requirements by growing tall and reaching light near the surface while the roots are in lake bottom below the area of minimum light requirements (Bronmark and Hansson 2005).

Algae – During the 2004 and 2005 sampling rounds, chlorophyll a, uncorrected for pheophytin ranged from 2.2 to 14.3 ug/l with the largest values (10.1 to 14.3 ug/l) occurring from June through September and the lowest values (2.2 to 6.9 ug/l) occurring from February through April when ice covered the lake. No algal masses were seen during any sample round.

Discussion – In the following discussion, Branmark 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 specially 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 similar to the lake processes in Bridger Lake with a few differences. During the summer, the lake has temperature stratification at about two meters and in the autumn, the water temperatures even out. However, the oxygenated water does not circulate to the bottom into the deeper strata. This is probably due to the shallowness of the lake, the short summer season, the lack of light below 2 to 2.5 meters, and the amount of macrophytes throughout the lake bottom that consumes oxygen below the 2-meter depth, which is the depth where the submerged macrophytes grow. A rapid decrease in dissolved oxygen occurs from the 2-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 respiration of plants due to lack of light when the ice is covered by snow and also no atmospheric oxygen has entered the water for a long time because of the long winter season.

Bronmark and Hansson (2005) also discuss oxygen fluctuations in shallow waters.

> "Organisms living in the littoral zone may also experience oxygen deficits during summer. In shallow areas with a high density of primary producers, such as

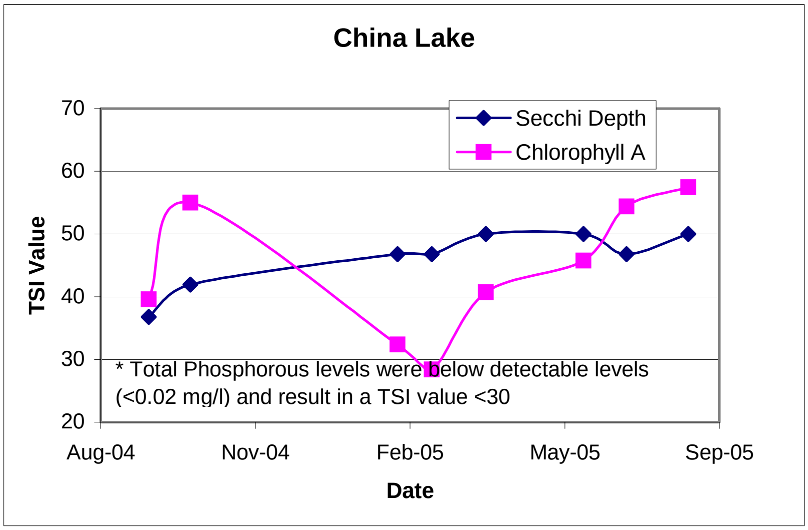
> submerged macrophytes and substrate-associated algae, dissolved oxygen levels change following a diel cycle. During daytime the photosynthetic activity is high in this well-lit habitat, resulting in high production of oxygen and saturation levels above 100%. During night-time, when the plants become ‘animals’, at least in the sense that they consume oxygen by respiration, dissolved oxygen in dense stands of submerged macrophytes may be severely reduced, In addition, in late summer when temperatures in shallow areas are high, decomposition processes may be so intense that plants start to die and oxygen cam be completely depleted, resulting in catastrophic die-offs, especially of fish, This phenomenon is termed ‘*summerkill*’.”

Although, oxygen in Bridger Lake is not completely depleted in the summertime, dissolved oxygen drops rapidly from the upper part of the submerged macrophyte layer to the lake bottom.

China Lake

Trophic State – Based on chlorophyll-a sampling in 2004 and 2005, the trophic state in China Lake varies seasonally (Figure 12). In mid-summer to early fall, the lake is eutrophic (TSI is 50-60), becomes oligotrophic in the winter (TSI is 30-40), then becomes mesotrophic in the spring (TSI is 40-50).

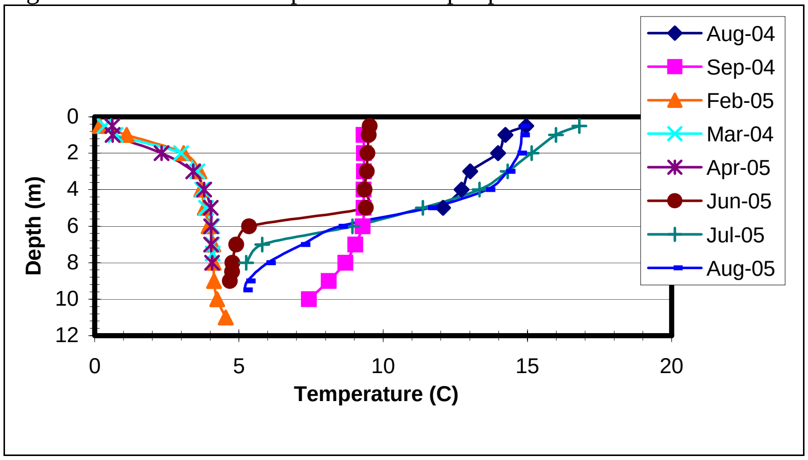
Figure 12. China Lake Trophic State Indices



Lake Morphology – China Lake is somewhat rectangular in shape with narrow extension for about 400 feet on the south end. The lake is about 600 feet wide, 2800 feet long including the narrow extension on the south end, and a mean depth of 20 feet.

Temperature – Based on sampling in 2004 and 2005, water temperatures in the depth profiles varies seasonally (Figure 13). In winter the water temperature is close to 0 degrees C at the surface and increases to 4 degrees C about 2.5 meters deep and continues at 4 degrees C to the bottom. From June to August, the water has a thermocline at the 5 to 6 meter depth. In autumn around September, the water temperatures decrease slowly with depth with temperatures at the surface about 9 degrees C and at the bottom about 7.5 degrees C.

Figure 13. China Lake temperature vs. depth profiles



Light (secchi depth) – For samples collected in 2004 and 2005, the secchi depth ranged from 2 to 5 meters. Between February and August 2005, most secchi depth readings were between 2 and 2.5 meters. During the winter of 2004-2005, ice was about two-feet thick and snow was about one-foot deep and lay upon the entire surface of the ice.

Catchment Area - The watershed above the lake is rather about 2,311 acres in size. The ground cover in the watershed is in good to excellent condition. The shore surrounding China Lake has a lodgepole overstory and in most areas the ground is covered with duff, grasses, and forbs that protect the soil surface from erosion. 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 (Bronmark and Hansson 2005).

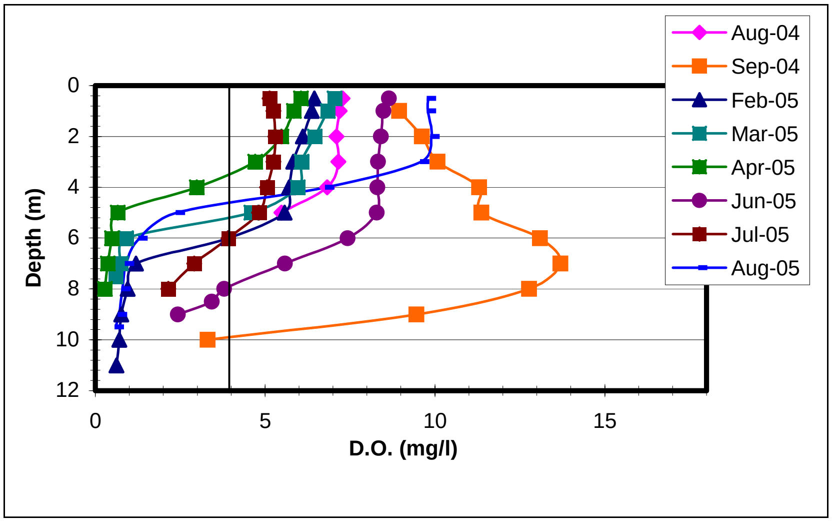
pH – For all levels sampled, the pH ranged from 6.1 to 8.5. The water near the lake bottom had a pH consistently between 6.1 and 6.5 and the water near the surface had pH readings between 6.6 and 7.0 in the winter/spring and between 7.5 and 8.5 in the summer/fall period. The pH of China Lake is tends to be slightly alkaline and is typical of most lakes of the earth. According to Bronmark and Hansson (2005), the majority of lakes on earth have a pH between 6 and 9.

Nutrients – For samples collected at the surface and mid-level point in China Lake, most samples have not exceeded the pollution indicator limit of 0.025 mg/l. Since August 1998, no total and only one dissolved phosphorus sample collected in the surface or mid-level sample has exceeded the pollution indicator limit. For samples collected at the bottom of the lake, more than half of the dissolved samples and almost all of the total samples have exceeded the pollution indicator limit. Dissolved nitrate and nitrite were not detected in most of the samples and in the samples where it was detected, the values were well below the pollution indicator value of 4 mg/l. In the small stream that flows into China Lake, total and dissolved phosphorus values were either not detected or below the pollution indicator value of 0.5 mg/l and dissolved nitrate and nitrite were not detected in any sample.

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. The phosphorus and total nitrogen concentration of China Lake is typical of most lakes unaffected by man since almost all samples of total phosphorus as P taken throughout that water column are below 0.1 mg/l and almost all dissolved nitrate + nitrite concentrations are below detection and those that have been detected have a highest value of 0.55 mg/l taken as a bottom sample.

Oxygen – From measurements collected 2004 and 2005, the dissolved oxygen profile shows stratification occurring throughout the year mainly at the 4 to 5-meter depth (Figure 14). Stratification was very pronounced during the winter months of February through April and in August 2005 where the dissolved oxygen levels were less than 1 mg/l below 5 and 6-meters. Dissolved oxygen in water at the surface ranged from 5.1 to 9.8 mg/l, then at 4 to 5 meters deep a rapid drop in dissolved oxygen occurs. At different times of the year, dissolved oxygen is below 4 mg/l at depths ranging from 3.5 to 13 meters. The dissolved oxygen levels are a few meters below the depth of light penetration as indicated by secchi depths of 2 to 3-meters and a rapid decrease in dissolved oxygen at about 5 to 6-meter depths.

Figure 14. China Lake dissolved oxygen vs. depth profiles



Macrophytes – Submersed macrophytes were growing in most of the lake bottom and free-floating macrophytes were found in the northern portion of the lake for about 200 feet from the shore. With a maximum depth of 14 meters, it is expected that macrophytes would grow throughout the bottom of the lake. Although light penetration is from 2 to 5-meters, plants can overcome the depth requirements by growing tall and reaching light near the surface while the roots are in lake bottom below the area of minimum light requirements (Bronmark and Hansson 2005).

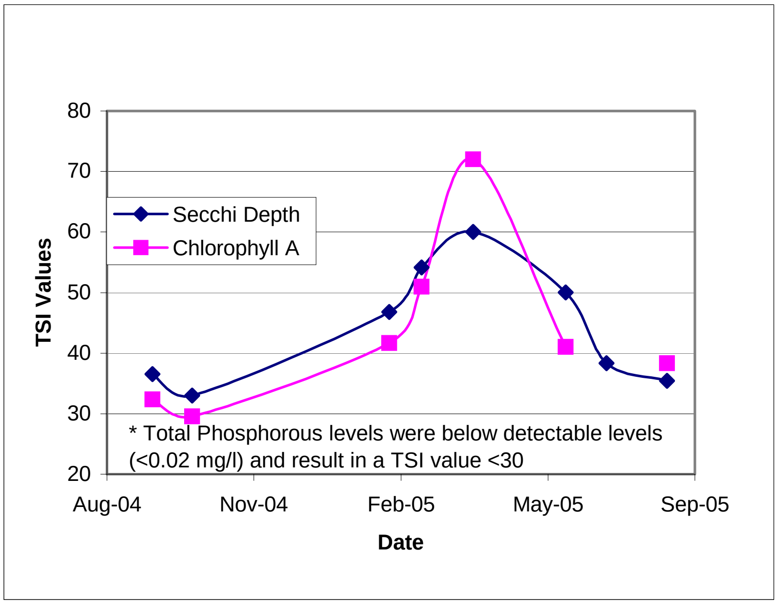
Algae – During the 2004 and 2005 sampling rounds, chlorophyll a, uncorrected for pheophytin ranged from 0.8 to 15.4 ug/l with the largest values (11.3 to 15.4 ug/l) occurring in July through September and the lowest values (0.8 to 4.7 ug/l) occurring from February through June. The very lowest values (0.8 to 2.8 ug/l) occurred during February through April when ice covered the lake. No algal masses were seen during any sample round.

Discussion – The water in China Lake follows the trends described in Branmark and Hansson (2005). In September, water temperature is unstratified at most of the water column is oxygenated with the exception of the very bottom two meters of the lake where dissolved oxygen drops rapidly. During the winter after ice forms, the temperatures of the water column are unstratified and close to 4°C while the dissolved oxygen is stratified with 2 to 3 meters below the ice having dissolved oygen levels above 5 mg/l but dropping rapidly to less than 1 mg/l below 5 to 6 meters. The secchi depth during this period is 2 to 3 meters indicating that dissolved oxygen is not replenished by photosynthesis and is being consumed by respiration most likely by the macrophytes in the lake bottom. Dissolved oxygen is stratified during the summer months and drops rapidly below the 5-meter depth. During this same time period, a thermocline occurs at the 4 to 5-meter level and light penetration is between 2 and 3.5 meters. It appears that macrophytes that are close to the water surface are capable of producing dissolved oxygen in the upper level of the lake but the lower portion of the lake remains at a low oxygen level.

Lyman Lake

Trophic State – Based on chlorophyll-a sampling between 2004 and 2005, the trophic state in Lyman Lake varies seasonally. From June through September, the trophic state went from slightly mesotrophic to oligotrophic. During the winter, the trophic state went from mesotrophic to hyper-eutrophic at the beginning of April. Lyman Lake was sampled in two areas and the same pattern was seen in both sites.

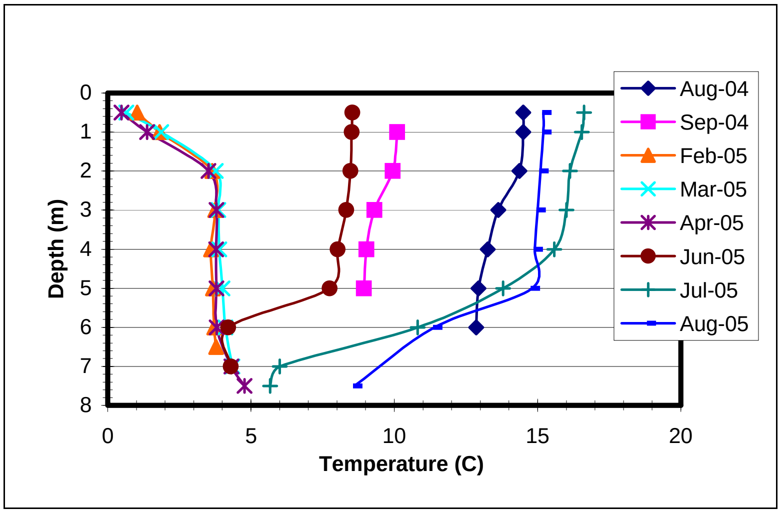
Figure 15. Lyman Lake Trophic State Indices



Lake Morphology – Lyman Lake is somewhat rectangular in shape and is about 700 feet wide, 2,300 feet long, and has a mean depth of 10 feet.

Temperature – Temperature varies both seasonally and in depth based on measurements taken from 2004 through 2005 (Figure 16). In August and September 2004, temperature dropped steadily from the surface to the bottom (5 to 6 meters deep) from 14.5 to 13 degrees C in August and 10 to 9 degrees C in September. In winter 2005, temperatures below the ice to the bottom stayed close to 4 degrees C. In June through August 2005, a thermocline developed at the 4 to 5-meter depth.

Figure 16. Lyman Lake temperature vs. depth profiles



Light (secchi depth) – From measurements taken in 2004 and 2005, the secchi depth ranged from 1 to 6.5 meters where during the winter the secchi depth was between 1 and 2.5 meters and during the spring summer and autumn the secchi depth was between 4.6 and 6.5 meters. During the winter of 2004-2005, ice was about two-feet thick and snow was about one-foot deep and lay upon the entire surface of the ice.

Catchment Area - The watershed above the lake is about 386 acres in size. The ground cover in the watershed is in good to excellent condition. The shore surrounding Lyman Lake has a lodgepole overstory and in most areas the ground is covered with duff, grasses, and forbs that protect the soil surface from erosion. 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 (Bronmark and Hansson 2005).

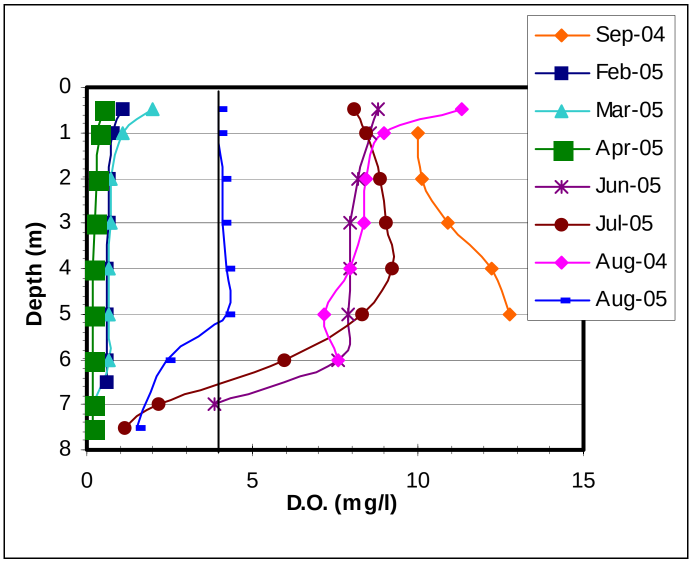
pH – Based on measurements taken from 2004 through 2005, pH varies both seasonally and by depth similar to temperature as described above. At the water surface, the pH increases from 8.1 to 8.8 from June to September then drops to about 7.5 from February through April. The pH at the bottom of the lake ranges from 6.9 to 7.4 throughout the year except for August 2004 where the pH value at the bottom was about 8.1. The pH of Lyman Lake is tends to be slightly alkaline and is typical of most lakes of the earth. According to Bronmark and Hansson (2005), the majority of lakes on earth have a pH between 6 and 9.

Nutrients – Dissolved total and total phosphorus were not detected for most of the samples collected between 1992 and 2005. The pollution indicator criteria of 0.025 mg/l was exceeded for dissolved total phosphorus samples collected at the surface in August 1981 and September 2002 and at the bottom in July 1995 and September 2002. The pollution indicator criteria of 0.025 mg/l was exceeded for total phosphorus samples collected at the surface in August 1981 and April 2005. Dissolved nitrate and nitrite were not detected in most of the samples and in the samples where it was detected, the values were 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. The phosphorus and total nitrogen concentration of Lyman Lake is typical of most lakes unaffected by man since almost all samples of total phosphorus as P taken throughout that water column are below 0.1 mg/l and almost all dissolved nitrate + nitrite concentrations are below detection and those that have been detected have a highest value of 0.5 mg/l taken as a bottom sample.

Oxygen –Almost all of the dissolved oxygen profiles from spring to autumn show a rapid drop in dissolved oxygen at the 5-meter depth and at the 6 to 7-meter depth dissolved oxygen concentrations are either below or approaching the 4 mg/l dissolved oxygen criteria.

Figure 17. Lyman Lake dissolved oxygen vs. depth profiles



Macrophytes - Submersed macrophytes were growing in most of the lake bottom and free-floating macrophytes were found in a small part of the shallow southwest portion of the lake for about 50 feet from the shore. With light penetration of 4.5 to 6.5-meters during the summer season, it is expected that macrophytes would grow throughout the bottom area of Lyman Lake which has a maximum depth of seven meters.

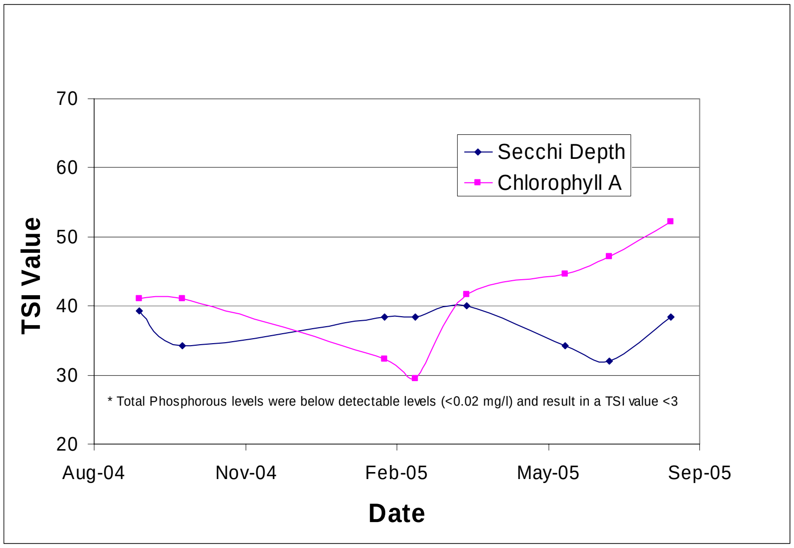
Algae - During the 2004 and 2005 sampling rounds, chlorophyll a, uncorrected for pheophytin ranged from 0.9 to 90.0 ug/l with the largest value occurring in February. Other than the high value in February, chlorophyll a values ranged from 0.9 to 3.9 ug/l. No algal masses were seen during any sample round.

Discussion – Lyman Lake has a similar trend as described in Branmark and Hansson (2005). In the autumn, the water temperature profile is unstratified and dissolved oxygen appears to be mixed throughout the lake. In winter the temperature profile is unstratified and close to 4°C through most of the water below the ice. Dissolved oxygen at this time drops to les than 1 mg/l through most of the water column below the ice layer. At the same time the secchi-depth drops from 2.5 meters in February to 1 meter in April. This indicates that the amount of light penetrating the water is very low and that respiration is much greater than photosynthesis and that dissolved oxygen is being used up during the long period of ice and snow cover. Dissolved oxygen levels in the upper layer of the lake is well oxygenated where light penetrates the surface to about 5 meters depth and the macrophyte plants are below the surface about 2 to 3 meters in depth.

Marsh Lake

Trophic State - The trophic state of Marsh Lake varies seasonally based on chlorophyll-a values from 2004 to 2005 (Figure 18). From spring to mid summer the lake is mesotrophic (TSI is 41 to 48) in late summer becomes slightly eutrophic (TSI is 52), and then in autumn it becomes mesotrophic again, and in winter it becomes oligotrophic (TSI is 30 to 32).

Figure 18. Marsh Lake Trophic Status

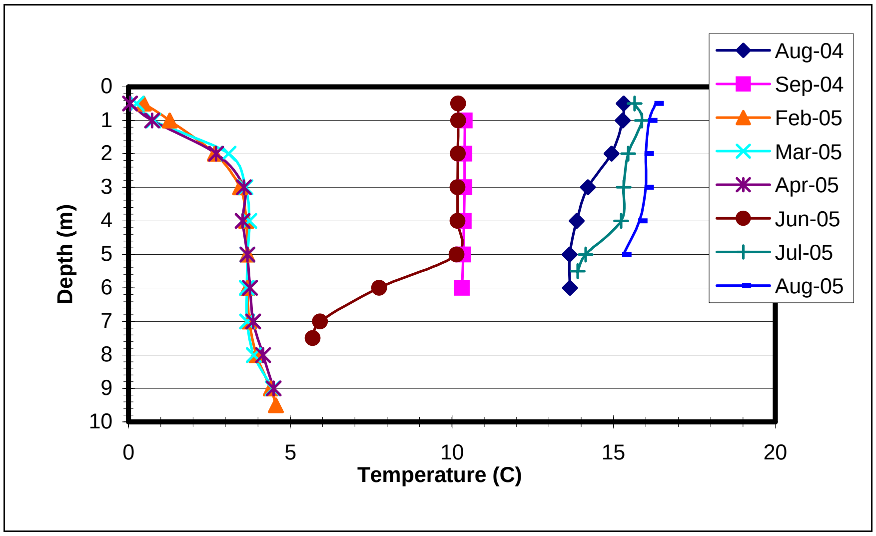


* Total Phosphorous levels were below detectable levels (<0.02 mg/l) and result in a TSI value <3

Lake Morphology – Marsh Lake is somewhat rectangular in shape and is about 600 feet wide, 3,600 feet long, and has a mean depth of 15 feet.

Temperature – Based on measurements from 2004 and 2005, temperature in Marsh Lake varies seasonally but remains fairly constant from the surface to the bottom (Figure 19). In winter, temperatures from the surface to 3 meters just below the ice increase linearly from about 0 degrees C to 4 degrees C then stays near 4 degrees C to the bottom. The only temperature stratification that was noted occurred in June when a thermocline developed at the 5-meter depth. In July through September, temperatures were fairly constant through the depth profile and ranged from 16 degrees C at the surface to about 13.5 at the bottom (6 meters). In September, the depth profile was constant at about 10.4 degrees C.

Figure 19. Marsh Lake temperature vs. depth profiles



Light (secchi depth) – Based on measurements in 2004 and 2005, the secchi depth ranges from 4 to 7 meters and varies seasonally. Between February and April, the secchi depth is between 4 and 4.5 meters and between June and September the secchi depth varies from 4 to 7 meters. During the winter of 2004-2005, ice was about two-feet thick and snow was about one-foot deep and lay upon the entire surface of the ice.

Catchment Area - The watershed above the lake is rather small, about 166 acres in size. No streams flow into it or out of it. The ground cover in the watershed is in good to excellent condition. The shore surrounding Marsh Lake has a lodgepole overstory and in most areas the ground is covered with duff, grasses, and forbs that protect the soil surface from erosion. 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 (Bronmark and Hansson 2005).

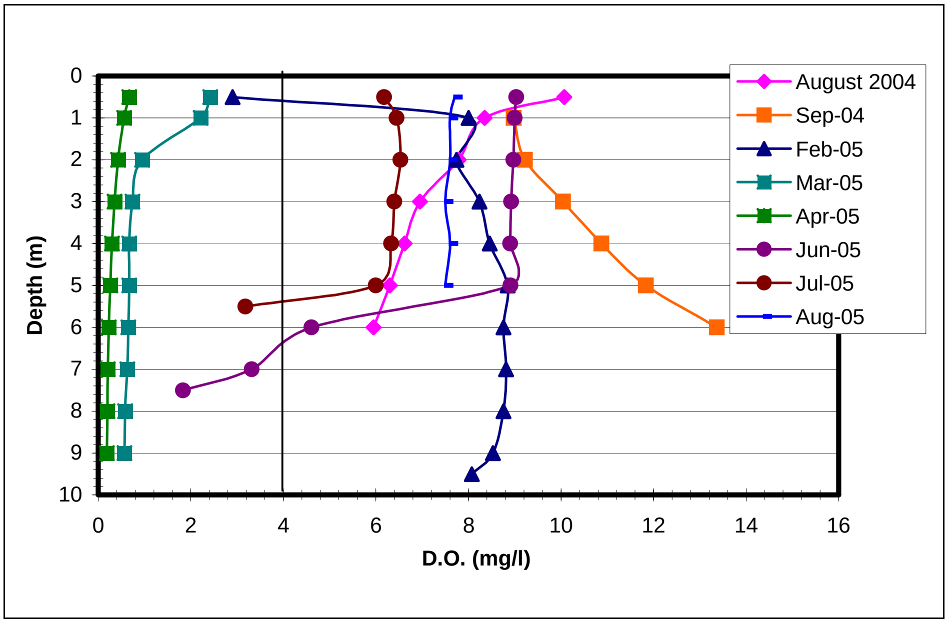
pH – The pH varies by season and by depth. From February to April, the pH values are similar throughout the depth profile ranging from 7.5 to 7.8. Between June and September, depths from the water surface to 5 to 6 meters the ph ranges from 8.2 to 8.8 and drops rapidly to 7.2 to 7.5 in June and July but stays constant between 8.4 and 8.7 to the bottom (6 meter depth) in August and September. The pH of Marsh Lake is tends to be slightly alkaline and is typical of most lakes of the earth. According to Bronmark and Hansson (2005), the majority of lakes on earth have a pH between 6 and 9.

Nutrients – Most of the total and dissolved total phosphorus values were below the detection limit for samples collected between 1989 and 2005. Dissolved Total phosphorus exceeded the pollution indicator criteria of 0.25 mg/l from the surface to the bottom in July 1997, at the surface in September 1997, and at the bottom in July 2003. Total phosphorus exceeded the pollution indicator criteria at the surface and bottom in June 1981 and at the bottom on several samples between 1989 and 1993 and in February, March, and April 2005. In March 2005, a mid-level sample also exceeded the pollution indicator criteria. Most of the dissolved nitrate and nitrite values were below detection limit and values above the detection limit were well below the pollution indicator criteria of 4 mg/l.

Bronmark and Hansson (2005) state that 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. Marsh Lake has total phosphorus values and nitrogen values that are typical of most natural lakes of the earth, particularly those in low nutrient coniferous forests.

Oxygen – For samples collected from 1995 to 2005, 11 of 15 sample rounds met the criteria of 50% of water column supporting 4 mg/l. Those sample rounds that did not meet the criteria occurred in July 1995, July 1997, and March and April 2005 (Figure 20). Dissolved oxygen varies by season and by depth. In June and July, the water is stratified at a depth of 4 to 5 meters where the dissolved oxygen from the surface to about 4 to 5 meters is between 6 and 9 mg/l at which point the dissolved oxygen rapidly decreases to below 4 mg/l at 6 meters and several samples were less than 1 mg/l below 7 meters. In August and September, the temperature change in depth occurs slowly and ranges from 5 to 8.5 mg/l. In February 2005, dissolved oxygen was fairly constant throughout the depth profile where dissolved oxygen just below the ice to the bottom ranged from 7.7 to 8.9 mg/l. In March and April 2005, the dissolved oxygen from just below the ice to the bottom was constant at values from 0.2 to 1.0 mg/l. In June and July 2005, the dissolved oxygen levels reflect the penetration of light to the depth at which photosynthesis can occur as indicated by secchi depths of six and seven meters and a rapid dissolved oxygen decrease at about 5 meters.

Figure 20. Marsh Lake dissolved oxygen vs. depth profiles



Macrophytes – Submersed macrophytes occur throughout the bottom of the lake and no surface macrophytes were seen. For a maximum depth in Marsh Lake of 10.5 meters, it is reasonable that macrophytes would grow throughout the lake bottom since the secchi depth is about 6 to 7 meters deep in the summer and plants can overcome minimum light requirements by growing tall in the water and reaching for the light (Bronmark and Hansson 2005).

Algae – During the 2004 and 2005 sampling rounds, chlorophyll a, uncorrected pheophytin ranged from 0.9 to 9.0 ug/l with the largest values (4.2 to 9.0 ug/l) occurring from June through August and the lowest values (0.9 to 3.1 ug/l) occurring from September through April. No algae masses were seen during the sample rounds.

Discussion - The changes in temperature and dissolved oxygen for measurements taken from Marsh Lake in 2004 and 2005 follow the trends described in Branmark and Hansson (2005) with some exceptions. In September, the temperature and dissolved oxygen are unstratified indicating a mixing of the waters of the lake. At the formation of ice, dissolved oxygen becomes stratified as dissolved oxygen begins to decrease from low photosynthesis due to low light penetration. This continues for a long time into the spring and dissolved oxygen levels fall to below 1 mg/l throughout most of the water column. Measurements of dissolved oxygen taken during summer months between 1995 and 2005 show the dissolved oxygen values rapidly drop to below 4 mg/l at depths of about 5 to 6 meters, the depth at which a secchi disk is not visible.

7.0 Use Attainability Analysis

As discussed in Section 2, dissolved oxygen impairment appears to be naturally occurring and not caused by man's activities for Bridger, China, Lyman and Marsh Lakes within the Wasatch-Cache National Forest. The results of the data and land management activities in their watersheds indicate that natural processes are causing the dissolved oxygen impairment during the winter season. Since man-made activities have not caused the impairment, Bridger, China, Lyman, and Marsh Lakes are recommended to be placed in Category 4C of the State of Utah's 303d List as not impaired by a pollutant.

8.0 Management Options and Practices

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. 1993).

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.

Since no man-made pollution has been found to contribute to dissolved oxygen impairment during the winter season, no allocation of loads, controls applied to them, or additional land management practices are recommended.

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