BIG EAST LAKE

LIMNOLOGICAL ASSESSMENT OF WATER QUALITY

March 2008

Big East Lake Report
March 6, 2008

Big East Lake is listed by the State of Utah as an impaired waterbody because dissolved oxygen does not meet State water quality standards. In partnership with Utah Division of Water Quality (UDWQ), the Uinta National Forest (WCNF) collected data from Big East Lake from August 2004 to August 2005 to provide recent detailed water quality information to support a Total Maximum Daily Load (TMDL) analysis. This report contains information listed below.

- Sections 1.0 and 2.0: Description of the waterbody and associated watershed, the nature of the impairment and water quality standards for the parameters of concern for the waterbody.

- Section 3.0: Discussion of whether the impairments are naturally occurring and, if not, what waterbody targets and endpoints are 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.

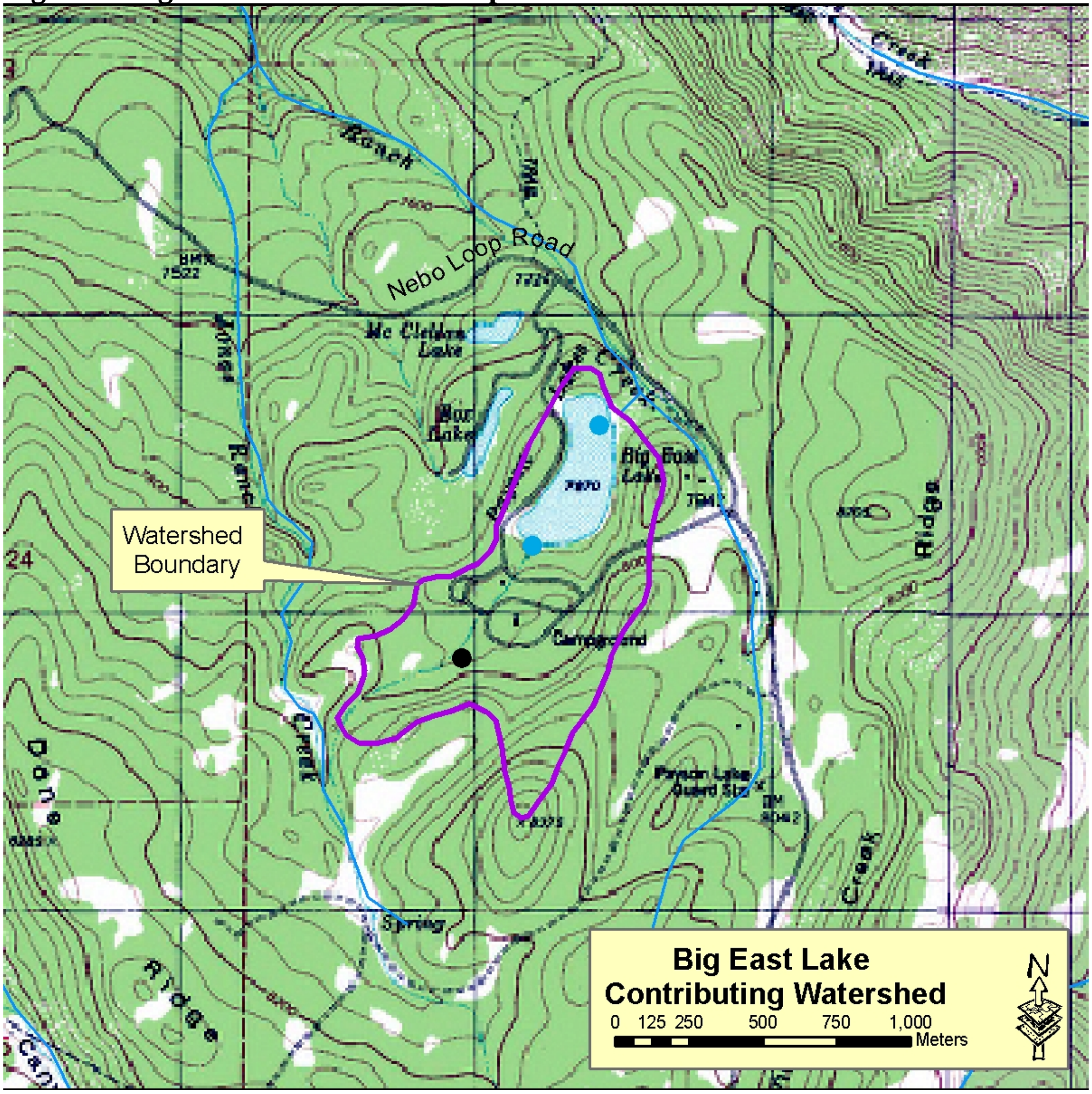
- Section 5.0: Identification of significant pollutant sources through use of existing information (maps, reports, inventories, and analyses) and new data.

- Section 6.0: Description of water quality data in relationship to abiotic and biological processes.

- Section 7.0: An evaluation of all sources contributing to impairment and a determination of beneficial use support.

- Section 8.0: The rationale for addressing all sources and causes that are significant for the attainment of water quality targets.

Figure 1. Big East Lake Location Map



1.0 Introduction

Big East Lake is a natural waterbody with a man-made dam. The lake was enlarged with the construction of a 30-foot tall earth-fill dam in 1898 for a water surface area of 23 acres with 4,092 feet of shoreline. Water is used for irrigation, coldwater aquatic habitat and recreation. The area is a popular summer recreational area for residents of Utah Valley. The Uinta National Forest maintains a large, staffed campground and day use facilities within the contributing watershed. A gravel-surfaced road provides access to the campsites and the road is well maintained and has proper drainage structures. Vault toilets recently have been installed on the drainage divide on the north-side of the lake. The toilets appear to be functioning properly. A small hiking trail is located about twenty feet from the shore of the lake.

The lake has a small contributing watershed of 183 acres, which, except for the diversion canal, is mostly unmodified by direct human activity. Vegetation within the watershed consists primarily of aspen, oak, meadow grass, and spruce-fir forest. The watershed high point, a point on the Nebo Loop Road 1.5 miles south of the lake, is 2,566 m (8,420 feet) above mean sea level. Annual precipitation ranges from 51-64 cm (20 - 25 inches) annually. Surface inflows into the lake include a spring-fed diversion from Jones Ranch Creek and flows from a spring complex on the southern shoreline. Estimates of water flows into Big East Lake taken in 2006 range from 0.5 cubic feet per second (cfs) in June to 0.02 cfs in August. The outflow is a short, unnamed creek that joins Wimmer Ranch Creek.

The contributing watershed is composed of gentle mountains, and is completely underlain by the Tertiary Moroni Formation. This unit is a combination of extrusive volcanics (pumice, tuff, andesitics) interbedded with conglomerates, sandstones, and limestones. A number of sedimentary clasts are typically included; Oquirrh Formation, Diamond Creek Sandstone, and Park City Formation. The Park City Formation is known to have high levels of naturally occurring phosphorus.

The ground cover in the watershed is in good condition. The shore surrounding Big East 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.

2.0 Water Quality Standards

This section discusses the associated impairment with respect to state water quality standards related to narrative criteria, numeric standards, antidegredation policies, designated beneficial uses, and the parameters of concern on the 303(d) listing.

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

Big East Lake is listed as impaired for dissolved oxygen for Cold Water Species of Game Fish (Beneficial Use Class 3A). The methodology for listing this parameter is described below.

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

Table 1. Utah's dissolved oxygen criteria for class 3A waters

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	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):

In addition, an evaluation is made 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. 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 waterbody in question. If a waterbody shows that beneficial use impairment consistently exists, the waterbody should be listed on the 303(d) list. However, if a waterbody exhibits a mixture of partially and fully supporting conditions over a period of years, the waterbody should continue to be evaluated.

An assessment of the water quality conditions in Big East Lake in 1997 (Judd 1997) is described below.

> The water quality of Big East Reservoir (Payson Lake) is good. It is considered soft with a hardness concentration of approximately 69 mg/L. The water quality constituents analyzed that exceeded

established State water quality standards for the reservoir were phosphorus, temperature, dissolved oxygen, and iron. The average concentration of total phosphorus in the water column during the productivity season exceeded the recommended level of 0.025 mg/L for all three study periods. Although the concentration at the surface 20, 34 and 26 ug/L averages just over the recommended level, the concentration throughout the water column was well over the limit with an average of 47 ug/L. Temperature values are within the limits for a cold water fishery early in the year, but late in the summer season temperatures throughout the water column rise to near the threshold value of 20^{o}C in the lake profiles for late summer. Dissolved oxygen concentrations decline in the water column to a point that exerts a stress on the fishery as indicated in the June 28, 1993 profile. The only other constituent that violates standards is iron. Of five samples obtained only once did iron exceed the standard (1000 ug/L). It appears that the major water quality problem is the elevated levels of nutrients which lead to overproduction and a loss of dissolved oxygen due in part to the decomposition of organic matter from the increased algal production. Due to relatively low nitrogen/phosphorus ratios the reservoir is classified as a nitrogen limited system. In 1981 and 1989 the reservoir was classified as an eutrophic reservoir. However, the data obtained in 1991 supports a mesotrophic classification. The reservoir has declined from a TSI index value of 55.28 (1981) to 48.41 (1991). This suggests that water quality is improving, but additional monitoring will be needed to verify the trend. The reservoir was stratified in 1981 and stratification was evident in 1991 and 1993. Typically, macrophytes have posed no problems at Big East Lake.

The DWR stocks the pond annually with 8,000 catchable rainbow trout (*Oncorhynchus mykiss*) in the spring and 4,000 in the fall. Fingerling brook trout (*Salvelinus fontinalis*) are occasionally planted (5,000 in 1989 and 1991). The lake was chemically treated by the DWR in 1957, so populations of native fishes may not be present.

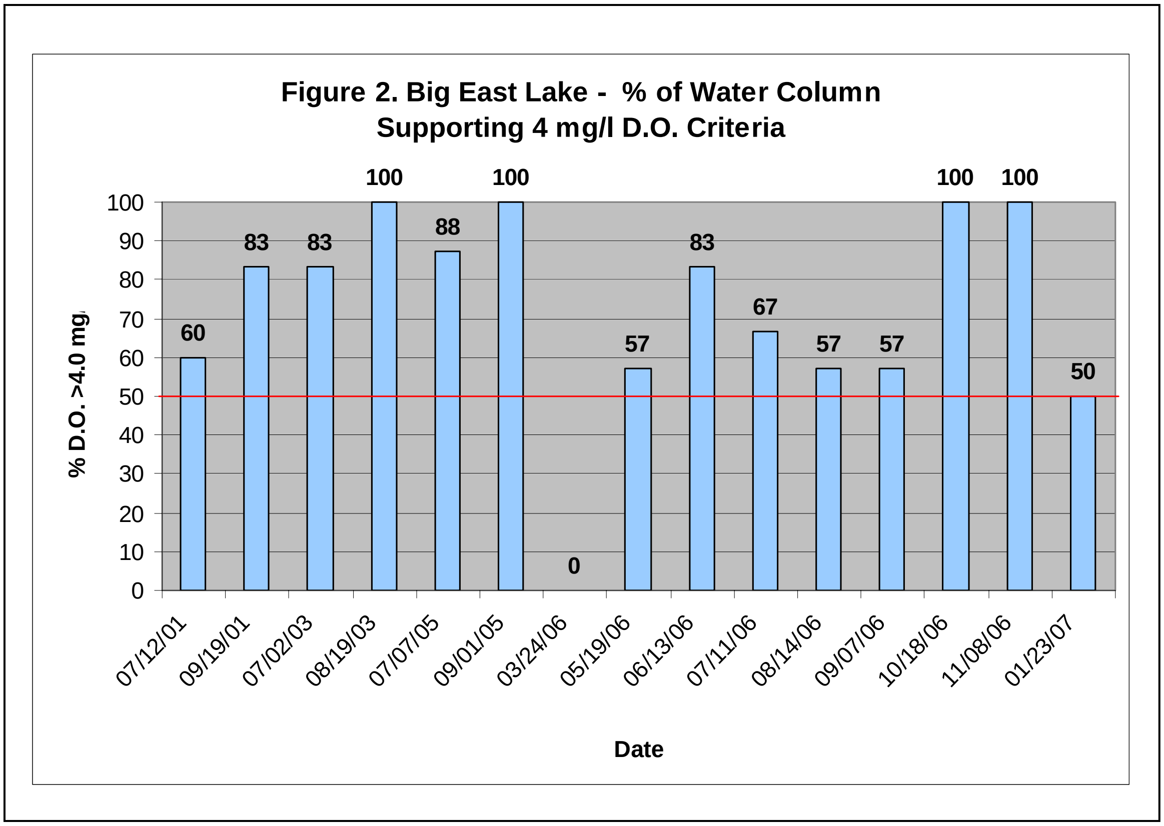
The phytoplankton is dominated by the blue-green algae, *Gloeotrichia echinulata*. These types of algae are more indicative of eutrophic conditions.

Pollution Assessment
Nonpoint pollution sources include the following: Human waste, litter and chemicals from recreation, and sedimentation, nutrient loading and pathogens from grazing. There are no point sources of pollution in the watershed.

Table 2 shows the 303(d) listing for Big East Lake. Dissolved oxygen impairment occurs during the winter season when the water column is below 4 mg/l in 50 percent or more of the water column. Based on measurements from 2001 through 2007, 14 of 15 water column profiles met the 4 mg/l dissolved oxygen criteria. The March 2006 the entire profile was anoxic from the surface to the bottom of the lake.

Table 2. Utah 2004 303(d) Listing for Big East Lake.

Waterbody	Waterbody Size	Beneficial Use Impaired	Pollutant or Stressor
Big East Lake	23 acres	3A Cold Water Species of Game Fish	Dissolved Oxygen



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.

Big East Lake appears to be acting under natural processes. The geologic formations in the contributing watershed contain strata that have high levels of naturally occurring phosphorus. A spring is the source of water to the stream that flows into the reservoir and the phosphorus that is detected in the stream is almost entirely in the dissolved fraction indicating the phosphorus is from groundwater sources and not from surface erosion or sedimentation. No man-made features appear to be contributing sediment to the lake and the vault-toilet restrooms are functioning properly. It appears that dissolved oxygen deficits occur in the winter as a result of stimulated plant growth from natural phosphorus inputs to the lake. Dissolved oxygen levels drop as a result of several factors including bacterial decomposition and decreased photosynthesis due to ice and snow cover and .

4.0 Beneficial Use Assessment

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

Land management activities do not appear to be contributing to the low dissolved oxygen concentrations during the winter season. The potential man-made sources of pollution are the campground road, the lake trail, and restrooms; and these appear to be well-maintained and properly controlling sediment and human wastes. Ground cover, which is an indicator of how well soil is protected from erosion, is good to excellent in the drainage above the lake and there is very little evidence of soil erosion around the lake. As discussed later in Section 8.0, several projects to aerate water in lakes of northern Utah have not been successful. No management actions are recommended at this time because the lake is functioning under natural processes. Impairment occurs during the winter when snow depths are high and respiration from macrophytes and bacterial decay naturally consume the oxygen in the lake.

5.0 Significant Sources

In order to identify sources of pollution, maps were reviewed to determine where surface water drains into Big East Lake and what and where man-made activities occur within the watershed.

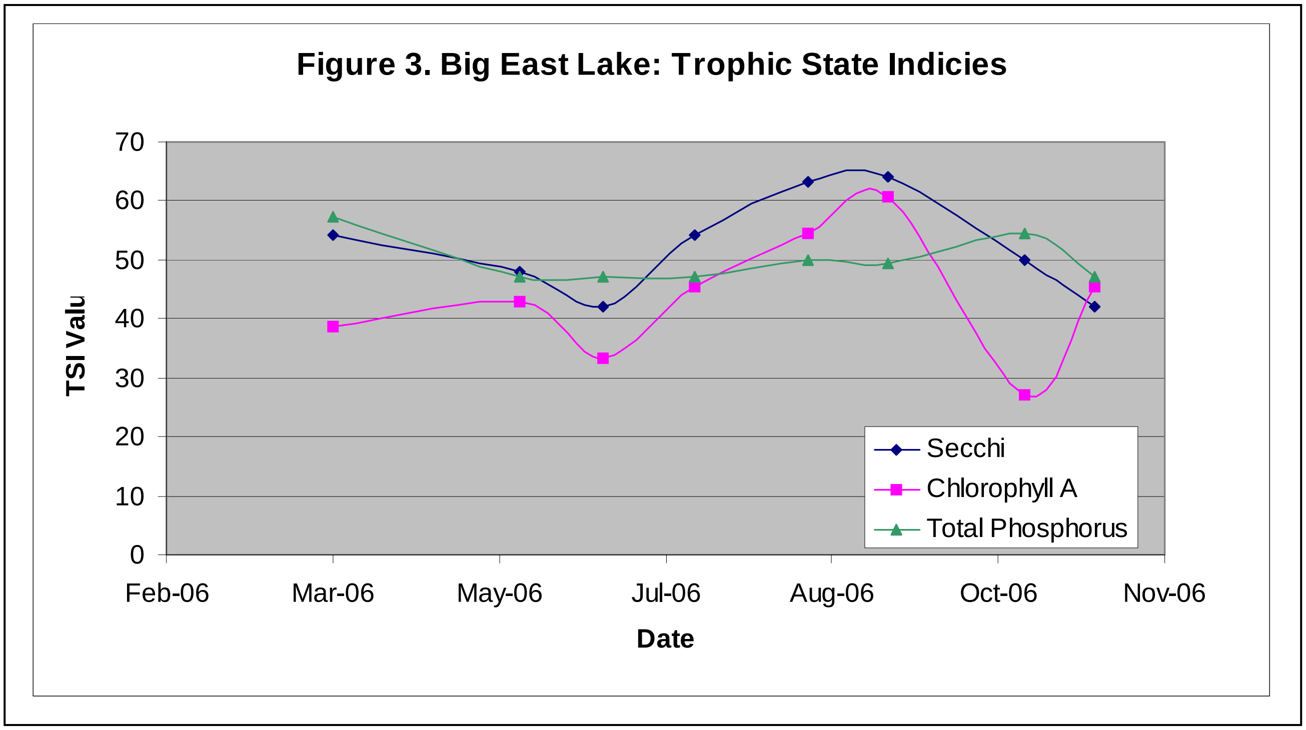
The potential man-made sources of pollution are the campground road, hiking trail, and restrooms. The campground road has a gravel surface and proper drainage and the hiking trail is narrow and does not appear to be contributing sediment to the lake. The restrooms are recently installed vault toilets and are currently functioning properly to contain human wastes.

6.0 Technical Analysis

This section contains a description of water quality data conditions at Big East Lake and 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 Big East 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 and transparency should be used only if no other parameter is available (Kent State 2005).

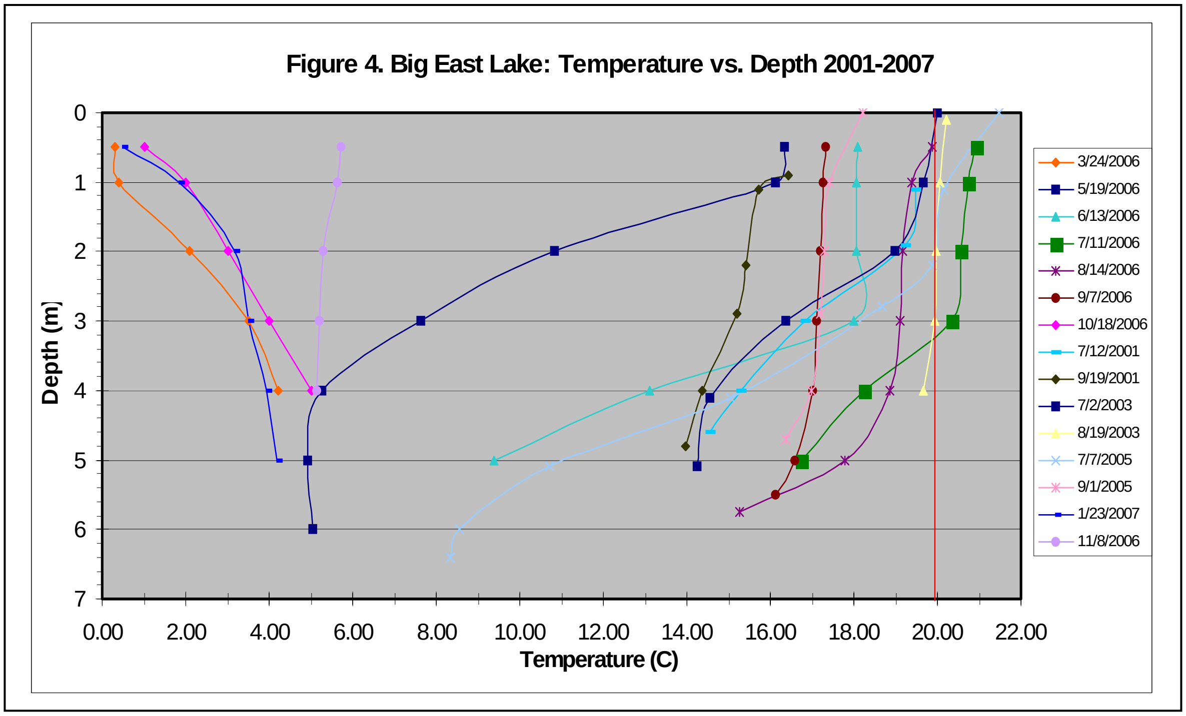
The trophic levels of Big East Lake based on chlorophyll-a and secchi disk have a similar seasonal pattern (Figure 3). The trophic levels based on the secchi disk are high mesotrophic in the spring and eutrophic in the summer. The trophic levels based on chlorophyll-a are low mesotrophic and high oligotrophic in the spring and eutrophic in the summer. Phosphorus could not be used for comparison because all of the samples were near or below the detection limit.



Carlson presents characteristics of northern 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). Big East Lake has these characteristics from February through June when the lake is mesotrophic and hypereutrophic.

Lake Morphology – Big East Lake is somewhat rectangular in shape and is about 840 feet wide, 1,690 feet long, and has a mean depth of 9 meters.

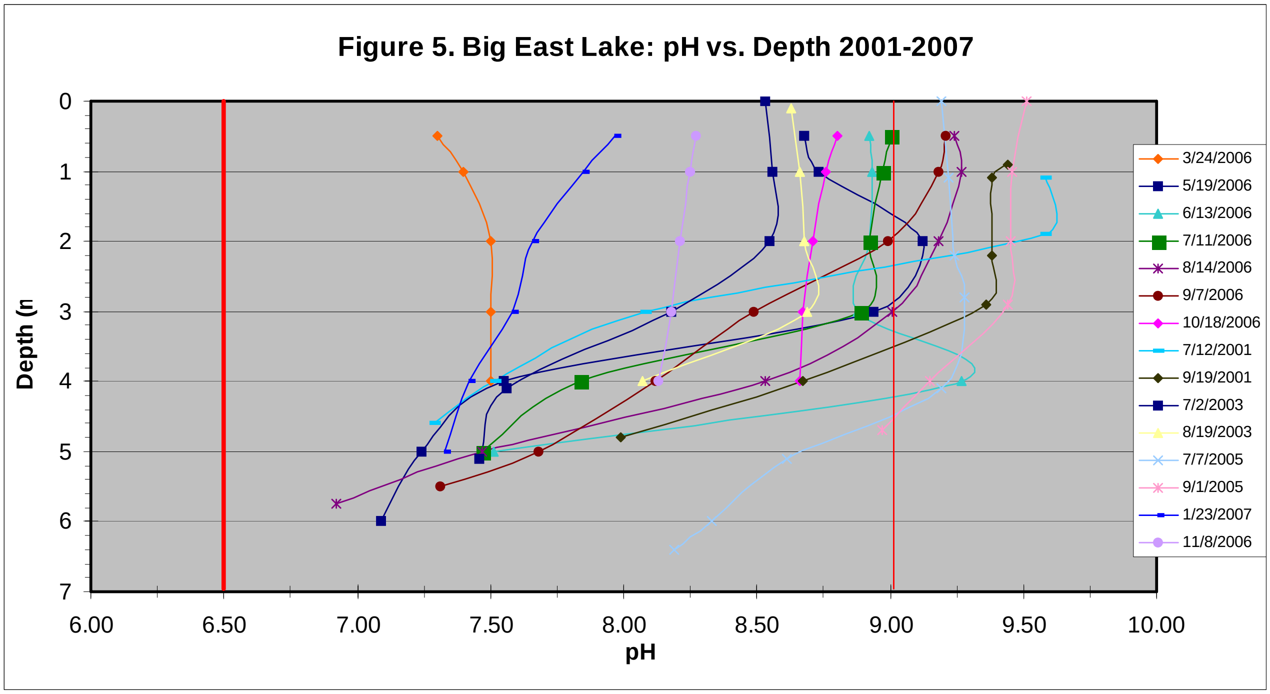
Temperature – Temperature varies both seasonally and in depth based on profile measurements taken since 2001. In June and July the lake is stratified with a thermocline at about 3 to 5 meters. In August and September the lake turns over and lake temperatures are unstratified until the following spring. Water temperature was just above the State standard of 20 degrees C in the top 3 meters in July 2006 and in the top 1 meter in July 2005 and August 2003. All of the other measurements were below the State standard. In 2006, the number of samples exceeding the State temperature standard is 4 of 55 (7% of the samples).



Light (secchi depth) – From measurements taken in 2006 and 2007, the secchi depth ranged from 0.8 meter during midsummer to 3.5 meters.

Catchment Area –The watershed above the lake is about 183 acres in size and located in the south end of the Wasatch Range Section which consists of Paleozoic rocks that have moved eastward to their present position along great thrust faults (Stokes 1986). The watershed is spruce fir forest and meadowlands. 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 since 2001, pH varies both seasonally and by depth. The pH varies at the water surface from 7.3 to 9.6 and at the bottom from 6.9 to 9.0. The pH of the water column tends to be more alkaline from the bottom to the surface . Based on 2006 measurements, pH is lowest during the winter and becomes increasingly alkaline until it peaks in August, at which time the pH of the water begins to drop.
The State standard for pH was exceeded in 16 of 36 measurements (44% of samples) prior to 2006 and in 7 of 55 measurements (13% of samples) in 2006 and 2007. Total number of pH exceedances since 2001 were 23 of 91 measurements (25% of samples).



Nutrients – Table 3 contains a summary of exceedances of the pollution indicator value of 0.025 mg/L and Table 4 contains the dissolved and total phosphorus and nitrogen concentrations in Big East Lake for samples collected since 1981. For calculating the following values, the assumption is made that a sample that had a non-detect was given a value of 0.01 mg/l which is one half the detection limit. In 2006, for all samples collected at all depths total phosphorus as P exceeded the phosphorus indicator of 0.025 mg/l in 9 out of 26 samples (35% of the samples). For all sampling events, the average concentration of total phosphorus as P at the surface (21) is 0.035 mg/l, above the thermocline (23) is 0.014 mg/l, below the thermocline (27) is 0.021 mg/l, and just above the bottom (29) is 0.065 mg/l. Most of the phosphorus in the stream inflow is in the dissolved fraction except during one sampling event in August 2006. For all samples collected, nitrogen as dissolved nitrite+nitrate was well below the standard of 4.0 mg/l and most of the samples (68%) did not detect nitrogen.

Table 3. Summary of Total Phosphorus exceedances and concentrations.				
Time Period	**Number of Exceedances**	**Number of Samples**	**Percent of Exceedances**	**Average Concentration (mg/l)**
1981 – 2005	22	49	44.9	0.044
2006	9	26	34.6	0.023
1981 - 2006	31	75	41.3	0.037

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

Table 4. Big East Lake nutrients concentration at various depths.

Date	Total Phosphorous as P (mg/L)				Dissolved Phosphorous as P (mg/L)				D-NO2+NO3, N (mg/l)			
	21	23	27	29	21	23	27	29	21	23	27	29
06/03/1981	0.020	--	--	0.040	--	--	--	--	--	--	--	--
05/30/1989	0.027	--	--	0.021	--	--	--	--	--	--	--	--
08/03/1989	0.040	--	--	0.086	--	--	--	--	--	--	--	--
03/22/1990	0.367	--	--	--	--	--	--	--	--	--	--	--
06/13/1991	0.012	0.0120	0.038	0.335	ND	ND	ND	0.313	0.068	0.067	0.059	0.032
08/08/1991	0.039			0.045	0.030	--	--	0.033	ND	--	--	0.017
06/28/1993	0.012	0.0170	0.054	0.064	0.015	ND	0.014	0.025	0.043	0.040	ND	ND
08/17/1993	0.016	0.0170	0.020	0.134	ND	ND	ND	0.030	ND	ND	ND	ND
06/20/1995	0.010	0.0100	0.020	0.050	ND	ND	ND	0.010	ND	ND	ND	ND
08/09/1995	0.010	0.0100	0.010	0.010	0.010	ND	ND	ND	ND	ND	1.100	ND
07/01/1997	--	--	--	--	0.031	0.050	0.056	0.104	ND	ND	ND	ND
08/26/1997	--	--	--	--	--	--	--	--	ND	ND	--	ND
06/30/1999	ND	--	--	0.022	ND	--	--	ND	ND	--	--	ND
09/16/1999	ND	ND	ND	0.037	ND	ND	ND	ND	0.020	0.020	0.020	0.410
07/12/2001	0.028	--	--	0.113	0.030	--	--	0.104	ND	--	--	ND
09/19/2001	0.036	--	--	0.156	0.026	--	--	0.062	ND	--	--	0.133
07/02/2003	0.032	--	--	0.039	ND	--	--	ND	0.370	--	--	ND
08/19/2003	0.048	--	--	0.043	0.023	--	--	ND	ND	--	--	ND
07/07/2005	0.021	ND	ND	0.037	ND	ND	ND	0.023	ND	ND	ND	ND
09/01/2005	ND	--	--	ND	ND	--	--	ND	ND	--	--	ND
03/24/2006	0.040	--	--	0.052	0.025	--	--	0.036	ND	--	--	ND
05/19/2006	ND	ND	ND	0.078	ND	ND	ND	0.024	ND	ND	ND	ND
06/13/2006	ND	ND	ND	0.026	ND	ND	--	ND	ND	ND	--	ND
07/11/2006	ND	ND	--	ND	ND	ND	--	0.122	ND	ND	ND	ND
08/14/2006	0.024	0.021	--	0.075	ND	0.022	--	0.028	ND	ND	--	ND
09/07/2006	0.023	0.024	0.030	0.088	0.025	0.087	0.025	0.061	ND	ND	ND	ND
10/18/2006	0.033	0.022	0.022	0.022	ND	ND	ND	ND	ND	ND	ND	ND
11/08/2006	ND	--	--	0.026	ND	--	--	ND	0.130	--	--	0.400

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).

between .004 and 1.5 mg/l. The phosphorus and total nitrogen concentration of Big East 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, 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.

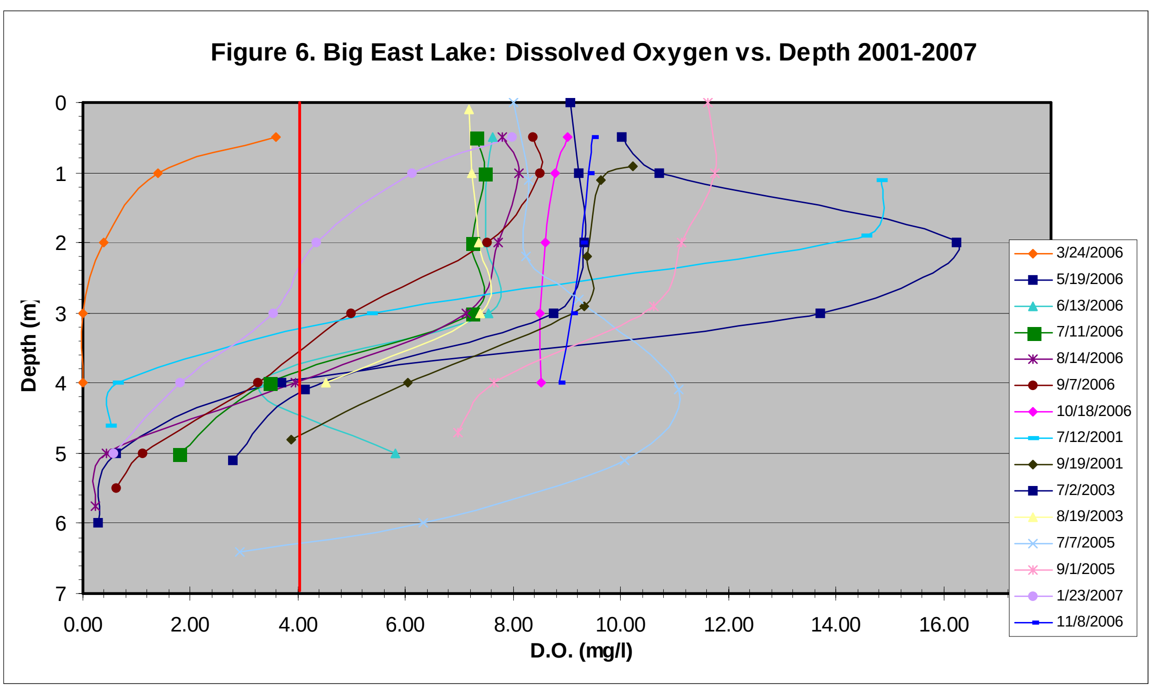
Table 5. Nutrient and field data for stream above Big East Lake (STORET 5917913).

Date	Time	Water Temp (C)	pH	DO (mg/l)	Spec. Cond. (S/cm^2)	Discharge (cfs)	Total Phosphorus as P (mg/l)	Dissolved Phosphorus as P (mg/l)	Dissolved Nitrogen NO2+NO3
01/23/2006	1200	1.24	8.49	12.10	197	0.50	----	----	----
03/24/2006	----	----	----	----	----	----	0.028	0.022	1.20
05/19/2006	1000	10.71	7.92	8.45	153	NR	0.035	0.024	0.84
06/13/2006	NR	10.09	8.08	7.91	183	0.29	0.035	0.031	1.03

07/11/2006	NR	9.36	8.04	7.80	182	0.08	0.035	0.022	1.13
08/14/2006	1040	8.31	8.10	6.95	193	0.54	0.080	0.031	1.20
09/07/2006	1040	8.54	8.14	7.95	192	0.02	0.062	0.059	1.13
10/18/2006	1200	1.24	8.49	12.10	197	0.50	0.028	0.022	1.20
11/08/2006	1200	5.20	8.20	9.59	200	0.50	0.035	0.030	1.51
01/23/2007	----	----	----	----	----	----	----	----	----

Note: NR means no sample collected. Red highlighted values exceed pollution indicator limit (0.05 mg/l for phosphorus and 4.0 mg/l for NO3+NO2). Samples were not collected in January 2006 and 2007 because water was frozen.

Oxygen – As shown in Figure 2, the percent of the water column supporting the 4 mg/l dissolved oxygen (DO) criterion range from 0 to 100 percent and 14 of the 15 profiles measured since 2001 have met the State standard of 50% of the profile above 4 mg/l DO. The only profile that did not meet the State standard was in March 2006 when the entire profile was below 4 mg/l DO. The DO profile changes seasonally with depth throughout the year. From measurements collected since 2001, the dissolved oxygen (DO) profile is stratified at the 3 to 5 meter depth. DO drops quickly at the 3-meter depth and continues to drop below the State standard at the 4-meter depth to the bottom at 6 meters. The DO profile is stratified until October when DO is found evenly throughout the profile. In November, the DO continues to drop throughout the profile until January when the bottom half of the profile is below the DO standard. In March 2006, the entire profile was below the State standard.



Before 2006, the dissolved oxygen in Big East Lake was below the standard of 4 mg/l in 5 out of 36 samples (14% of the samples). In 2006, the dissolved oxygen in Big East

Lake was below the standard of 4 mg/l in 20 out of 55 samples (36% of the samples). For all samples collected, the dissolved oxygen in Big East Lake was below the standard of 4 mg/l in 25 out of 91 samples (27% of the samples). All of the measurements were below the standard in the bottom 3 meters of the lake.

Macrophytes – During the 2006-2007 sampling rounds, macrophytes were seen growing in about two-thirds of the lake bottom mainly in the shallow areas of the lake.

Algae - During the 2006 to 2007 sampling rounds chlorophyll a, uncorrected for pheophytin, ranged from non-detect to 21.5 ug/l with the largest value occurring in September. A definite trend is seen where chlorophyll-a increases continuously from March to September then drops completely to non-detectable levels in October. No algal masses were seen during any sample round in 2006.

A taxonomic survey of phytoplankton was conducted on Big East Lake from a sample of the water column collected in August 2006. The results of this sample compared to those in the Judd (1997) inventory are presented in Table 6. The results from the 2006 sample indicate the phytoplankton community has increased in diversity from the 1997 sample which is indicative of improving water quality in the lake.

Table 6. Diversity measurements for Big East Lake.

Diversity Measure	**Judd (1997)**	**2006 Sample**
Shannon-Weiner Index	0.11	1.93
Species Evenness	0.04	0.75
Species Richness	0.44	2.23

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.

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

> "Lakes and wetlands also have distinctive biogeochemical characteristics with respect to their interaction with ground water. The chemistry of ground water and the direction and magnitude of exchange with surface water significantly affect the input of dissolved chemicals to lakes and wetlands. In general, if lakes and wetlands have little interaction with streams or with ground water, input of dissolved chemicals is mostly from precipitation; therefore, the input of chemicals

is minimal. Lakes and wetlands that have a considerable amount of ground-water inflow generally have large inputs of dissolved chemicals. In cases where the input of dissolved nutrients such as phosphorus and nitrogen exceeds the output, primary production by algae and wetland plants is large. When this large amount of plant material dies, oxygen is used in the process of decomposition. In some cases the loss of oxygen from lake water can be large enough to kill fish and other aquatic organisms.

The magnitude of surface-water inflow and outflow also affects the retention of nutrients in wetlands. If lakes or wetlands have no stream outflow, retention of chemicals is high. The tendency to retain nutrients usually is less in wetlands that are flushed substantially by throughflow of surface water. In general, as surface-water inputs increase, wetlands vary from those that strongly retain nutrients to those that both import and export large amounts of nutrients. Furthermore, wetlands commonly have a significant role in altering the chemical form of dissolved constituents. For example, wetlands that have throughflow of surface water tend to retain the chemically oxidized forms and release the chemically reduced forms of metals and nutrients."

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

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. Other high mountain lakes in northern Utah that have dissolved oxygen impairment are Bridger Lake, Marsh Lake, China Lake, and Lyman Lake located on the north side of the Uinta Mountains. Although they are not in the same geological type they are similar in that they are all located in relatively undisturbed watersheds with comparable weather patterns and aspect. All of these lakes have dissolved oxygen impairment that occur during the same winter-season, surface water flow from streams into the lakes are very low or non-existent, and 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.

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. If the ice is covered by a thick layer of snow, photosynthesis and oxygen production will be almost completely suppressed because of the lack of light. If this continues for a long period the oxygen in the lake may be completely depleted, resulting in massive fish mortality. This is called '*winterkill*' and is especially common in shallow, productive ponds and lakes where decomposition of large quantities of dead organisms consumes a lot of oxygen."

Big East Lake has a similar trend as described above. 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 and in late winter dissolved oxygen drops to less than 4 mg/l through most of the water column below the ice layer. At the same time the secchi-depth changes from 3.5 meters in November to 1.5 meters in March. 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.

7.0 Source Assessment

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

As discussed in Section 2.1, dissolved oxygen impairment appears to be naturally occurring and not caused by man's activities. The results of the data analysis and land management activities in the watershed indicate that natural processes are causing the dissolved oxygen impairment during the winter season. Since anthropogenic activities have not caused the impairment, Big East Lake is recommended to be placed in Category 4C of the State of Utah's 303d List as not impaired by a pollutant.

8.0 Best Management Practices

This section discusses the rationale for the means of addressing all sources and causes that are significant in the attainment of the TMDL endpoints/targets; the allocation of loads to those significant sources; a description of what controls will be applied and who will be responsible for applying them, and where and when they will be applied. In addition, this section discusses whether land management activities are contributing to the impairment and what practices may be recommended to reduce sources of impairment.

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 man-made lake conditions primarily in the hypolimnion during long periods of ice or snow and in dense macrophyte beds at night or following long periods of cloud cover. Approaches to alleviating low dissolved oxygen problems include decreasing the quantity of organic matter decomposing in the lake, increasing photosynthesis, destratifying the lake, and directly aerating the lake.

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

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

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

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

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