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HYDROLOGY OF BEAR LAKE BASIN AND ITS IMPACT ON THE TROPHIC STATE OF BEAR LAKE, UTAH-IDAHO

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ABSTRACT.—Bear Lake is a large, relatively pristine lake located in a graben valley. The lacustrine environment is more than 35,000 years old. Over that period of time, the Bear River intermittently flowed into Bear Lake. Approximately 10,000 to 8,000 BP, the Bear River ceased flowing directly into the lake. Between 1912 and 1924, channels were dug that diverted Bear River flows into the lake. An analysis was conducted to determine the impacts of Bear River flows upon the hydrologic and nutrient budgets of the Bear Lake ecosystem. In addition, the resulting limnological conditions were evaluated. Based upon eight years of historical data (1976 to 1984), regression relationships were developed that allowed an estimation of the historical conditions in Bear Lake (1923 to present) with and without the influence of the Bear River.

Bear Lake, located on the northern border of Utah, is a 282 km^2 natural body of water. The lake presently occupies most of the southern half of the Bear Lake Valley. The geology of the area was first mapped by Richardson (1913) and Mansfield (1927) and more recently by Armstrong and Cressman (1963), McClurg (1970), and Kaliser (1972). The Bear Lake basin is a graben valley bordered on the east and west by normal faults, with Mesozoic and Cenozoic rocks on the east and Paleozoic, Mesozoic, and Cenozoic rocks on the west. The exact age of the lake is presently unknown; however, stratigraphic studies by Robertson (1978) have verified previous morphologic interpretations by Mansfield (1927), which suggest a glacial age for the origin of Bear Lake. Robertson (1978) suggested the lake has had a continuous lacustrine history of at least 35,000 years (BP). However, unlike pluvial lakes Thatcher and Bonneville, which formed in closed basins and were therefore regulated by climatic fluctuations, the early conditions within the Bear Lake Valley remained opened with a northward drainage along the Bear River.

Over the last 28,000 years, the major water level fluctuations in the Bear Lake Valley have been the result of downcuttings of the northern valley outlet and two periods of faulting within the southern Bear Lake Valley. Early conditions within the lake indicated a widespread bay and marsh ecosystem. Tectonic activity lowered the valley differently, resulting in marshes and shallow bays occupying the northern Bear Lake Valley and a deep lake to the south (Robertson 1978). Current conditions have continued over the last 8,000 years with the present outlet of the Bear River northward along the east side of the valley. During most of this time, the lake has been isolated from the major drainage networks (primarily the Bear River). This has led to the occurrence of four endemic fish species that still inhabit the lake in large numbers, and a unique macrochemistry with magnesium as the predominant cation (Kemmerer et al. 1923).

At the present time, Bear Lake is no longer considered a closed basin. Its isolations ended in 1912 with the development of Stewart Dam, Lifton Station, and the diversion of the Bear River into Dingle Marsh. Although historically the marsh (and therefore the Bear River) was separated from the lake by a naturally occurring sandbar, it now serves as a water storage and transfer facility. Water is diverted from the Bear River into the marsh during spring runoff (March–July) and allowed to flow into Bear Lake. When irrigation demands increase during the summer, water flows into the marsh from Bear Lake and then into the Bear River downstream from the diversion dam.

Previous studies (Nunan 1972) have indicated that the storage of Bear River water has altered the macrochemistry of Bear Lake, reducing the TDS (total dissolved solids) levels

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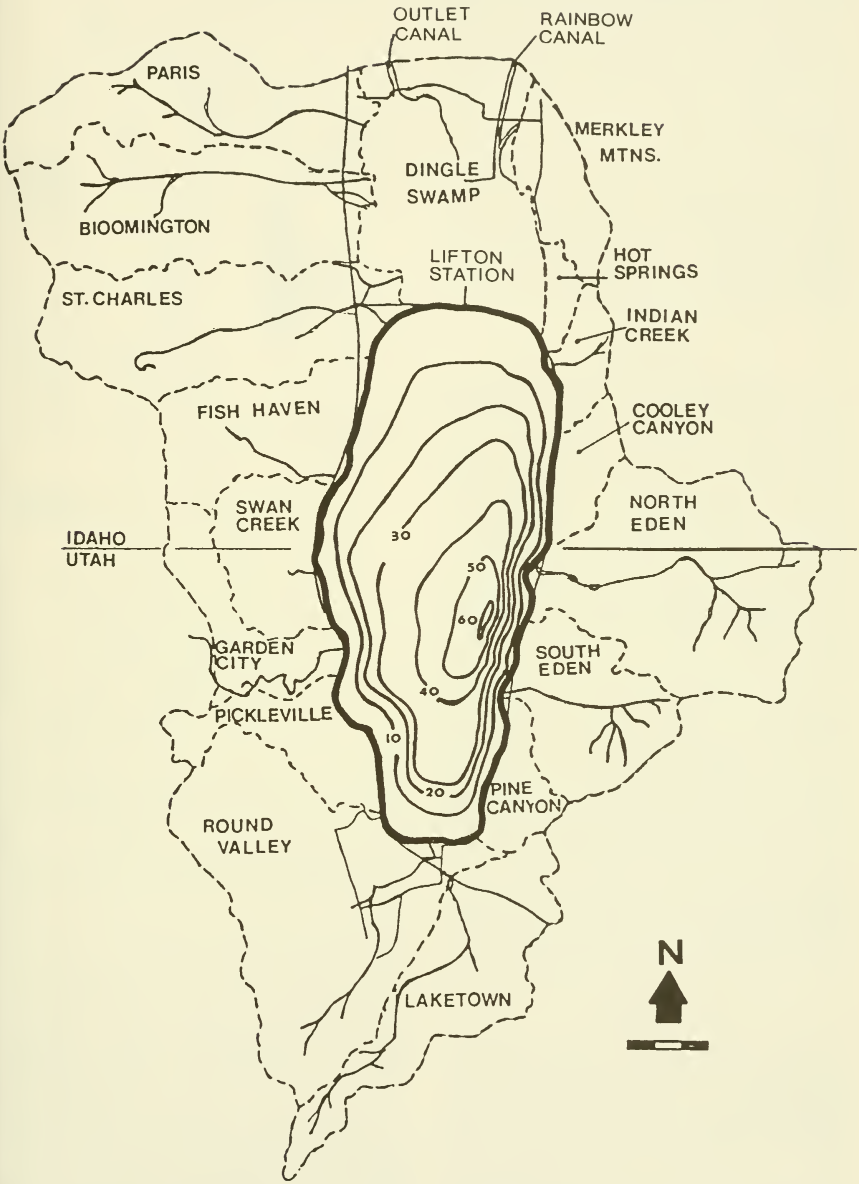

Fig. 1. Watershed and bathemetric map of Bear Lake, Utah-Idaho. Depth contours are in meters.

from over 1000 mg/l to 500 mg/l during a 50-year period. Recently Lamarra et al. (1984) has noted that the Bear River has also altered the trophic state of Bear Lake. Because of the dominant role of the Bear River in the historical as well as the current hydrological and limnological conditions of Bear Lake, a more detailed description of the impacts upon the lake is needed. It is therefore the purpose of this study to quantitatively describe the current impact of the Bear River upon the hydrology and trophic state of Bear Lake over the last decade and to empirically describe the historical conditions that have existed within the lake during the last 60 years.

Methods

To distinguish the water quality impacts of the Bear River from the historical Bear Lake watershed, mass nutrient loadings were determined for each major tributary basin and the Bear River (Figs. 1, 2). Water quality analyses (total phosphorus, total nitrogen, total organic carbon, ortho-phosphate, ammonia, nitrate, and nitrite) were performed according to standard methods (APHA 1980). Flow measurements were determined on site or obtained from Utah Power and Light Company.

Water samples were also collected at eight depths at a limnetic site corresponding to the deepest area in Bear Lake (63 m). Analyses included temperature, oxygen, pH, and conductivity in addition to the nutrients previously mentioned. Algal biomass (chlorophyll *a*) was determined by the Fluorometric procedure using a Turner Model III Fluorometer.

Meteorological data were obtained from the NOAA Station at Lifton. Water quality of rain events was previously determined (Herron et al. 1984) and used in this study.

Results

The Bear Lake ecosystem and its associated watersheds cover approximately 8,250 km^2, with 7,000 km^2 in the upper Bear River basin and the remaining 1,250 km^2 within the natural Bear Lake drainage. These major watersheds are within the states of Idaho, Utah, and Wyoming (Fig. 2) and lie within the Great Basin. The results of this study will be presented separately by drainage basin and Bear Lake limnology.

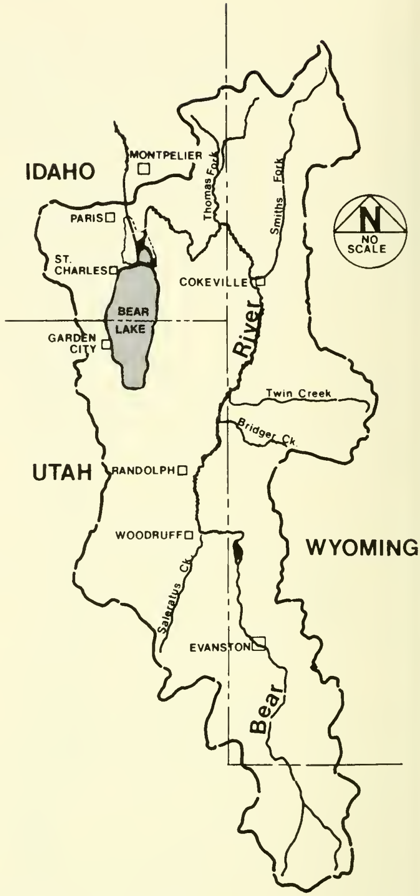

Fig. 2. A location map for Bear Lake and its watershed.

BEAR RIVER DRAINAGE.—A special portion of the Bear Lake watershed is located above the Dingle Marsh system. This watershed has only been impacting Bear Lake since 1912, when the Stewart Dam and the associated canal system was constructed. The water from the upper Bear River basin is diverted into Bear Lake during spring runoff (March–June). The annual flows at Stewart Dam for 1975 to 1984 can be seen in Figure 3. The dominant portion of the flows occurs between

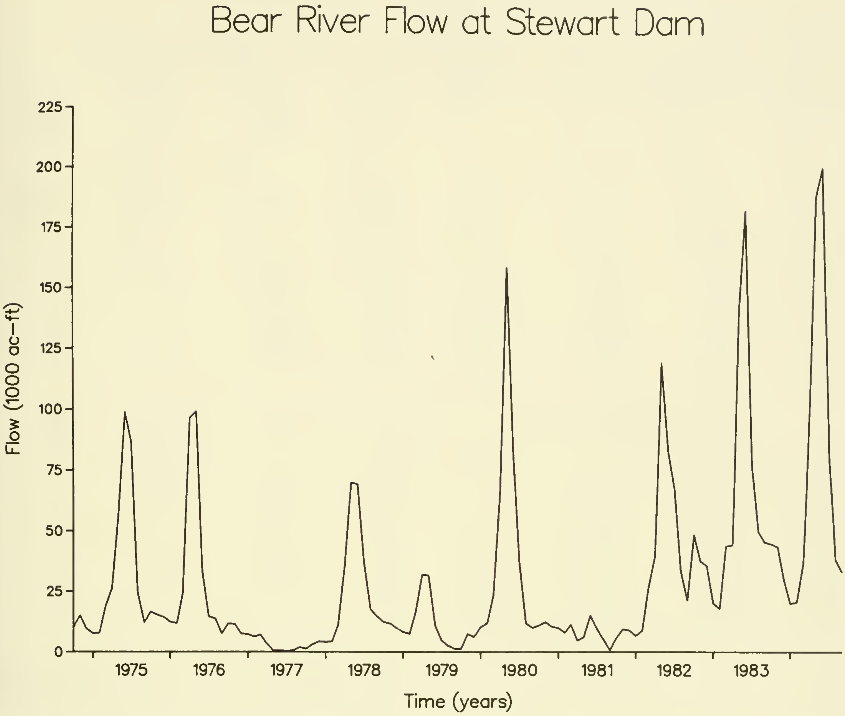

Fig. 3. The flow in the Bear River at Stewart Dam between 1975 and 1984.

March and June. In the last 10 years, the lowest volume entering the marsh was during 1977 (11,400 ac-ft) and 1981 (37,240 ac-ft). The highest volumes occurred in 1983 (411,330 ac-ft) and 1984 (492,400 ac-ft). Because of the water control structures present around the marsh, not all the water entering the system exits into Bear Lake during the spring period. For example, although 492,400 ac-ft entered Stewart Dam in 1984, 240,900 ac-ft was diverted through the outlet canal back into the Bear River, whereas the remaining 244,100 ac-ft was released through Lifton Station into Bear Lake (Table 1). The comparison of Lifton inflows to all other water sources into Bear Lake can be seen in Table 2 for the period 1975 to 1984.

Between 1975 and 1984 more than 66 sets of water quality data have been collected at the three key water control structures in Dingle Marsh (March to September). These data are also summarized in Table 1. The most complete data set are represented by total phosphorus and total inorganic nitrogen. The total phosphorus data at Lifton represents the mass loading by the Bear River into Bear Lake for 1975 and 1978 to 1984. The difference in the range of loading is significant, with 1981 being only 1,300 kg TP but 1983 being 25,838 kg TP. Ortho-phosphate was from 6.8% to 19.8% of the total phosphorus loading. In all cases, the marsh tended to remove phosphorus from the Bear River prior to its entrance into the lake. This was markedly different when compared to nitrogen and organic carbon (i.e., 1981, 1982, and 1984), when the marsh was in balance or actually increased the mass of these materials to the Bear River as it moved through the system.

BEAR LAKE WATERSHEDS AND PRECIPITATION.—Land in the Bear Lake watersheds has

TABLE 1. The mass movements of water and nutrients through key control structures around the Dingle Marsh system. The material moving through Lifton Station is the mass actually entering Bear Lake. (TP = total phosphorous; TOC = total organic carbon; TN = total nitrogen; TSS = total suspended solids; PO_4-P = orthophosphate; TIN = total inorganic nitrogen).

	Flow (AC-ftx1000) (March–June)		
Year	STD	LFT	Outlet
1975	119.61	179.34	20.27
1976	253.96	221.08	52.45
1977	11.43	9.77	111.11
1978	185.26	183.61	1.65
1979	90.36	86.44	22.28
1980	329.73	279.58	52.13
1981	37.24	34.03	28.79
1982	267.68	264.84	2.83
1983	411.33	251.50	198.97
1984	492.40	244.10	240.90

	Kg TP (March–June)		
Year	STD	LFT	Outlet
1975	11,367	9,982	10
1978	17,366	13,343	0
1979	20,669	8,551	1
1980	56,310	27,679	10
1981	6,068	1,300	3,480
1982	59,151	18,460	254
1983	75,951	25,838	26,403
1984	115,450	23,680	51,990

	Kg TOCx1000 (March–June)		
Year	STD	LFT	Outlet
1975	—	—	—
1978	—	—	—
1979	—	—	—
1980	—	—	—
1981	328	290	432
1982	3,310	7,808	32
1983	—	—	—
1984	—	—	—

	Kg TN (March–June)		
Year	STD	LFT	Outlet
1975	—	289, 042	—
1978	—	—	—
1979	—	—	—
1980	—	—	—
1981	20,693	16,579	29,284
1982	231,175	153,438	2,219
1983	578,087	137,337	138,669
1984	834,370	183,645	234,241

	Kg TSSx1000 (March–June)		
Year	STD	LFT	Outlet
1975	—	—	—
1978	—	—	—
1979	—	—	—
1980	—	—	—
1981	2,289	456	1,396

Table 1 continued.

	Kg TSSx1000 (March–June)		
Year	STD	LFT	Outlet
1982	63,403	13,388	193
1983	38,535	18,850	12,586
1984	73,991	22,655	41,645

	Kg PO_4-P (March–June)		
Year	STD	LFT	Outlet
1975	—	1,602	—
1978	—	—	—
1979	2,703	582	.08
1980	13,442	5,494	0
1981	249	195	376
1982	4,263	1,244	20
1983	16,188	3,777	2,883
1984	5,435	1,155	3,151

	Kg TIN (March–June)		
Year	STD	LFT	Outlet
1975	—	27,721	—
1978	54,951	33,877	0.40
1979	15,323	13,965	1.00
1980	83,485	30,347	0
1981	5,193	3,173	4,042
1982	61,847	30,257	471
1983	24,791	12,607	6,968
1984	68,475	29,286	36,536

traditionally been used almost exclusively for rural-agricultural purposes. The high mountain lands are used primarily for grazing, watershed protection, and some recreation, whereas the land uses in the foothills surrounding the lake are grazing, dry farming, and recreational home sites. The valley floor adjacent to the lake is used for irrigated croplands, pasture for native grasses, and the major sites for summer homes and subdivisions, which are being developed at a rapid rate. The tributary discharges from the watershed for the years 1975 to 1984 can be seen in Table 2 and Figure 4. As with the Bear River, 1977 and 1981 were dry years and 1983 and 1984 were wetter than average. The associated total phosphorus budgets for these watersheds can be seen in Table 3. As can be seen from these data, 13% of the total phosphorus input into Bear Lake is by wet fall from atmospheric precipitation, whereas 20% is from the endemic watershed. The vast majority (67%) is from the Bear River at Lifton. The areal phosphorus loading (g P/m^2 Bear Lake surface/year) ranges from 0.045 g P/m^2/year to 0.136 g P/m^2/year for the five years studied.

TABLE 2. The hydrologic inputs to Bear Lake between 1975 and 1984.

Year	Flows (ac-ft x 1000)						
	Bear River (Lifton) %		Bear Lake watersheds (%)		Precipitation (%)		Total
1975	179.34	(48)	140.6	(37)	55.6	(15)	375.5
1976	221.1	(53)	119.3	(29)	74.6	(18)	415.0
1977	9.8	(8)	49.2	(41)	61.3	(51)	120.3
1978	183.6	(47)	127.6	(33)	76.5	(20)	387.7
1979	86.4	(39)	98.8	(44)	37.3	(17)	222.5
1980	279.6	(51)	174.1	(32)	96.2	(17)	549.9
1981	34.0	(23)	60.5	(41)	52.8	(36)	147.3
1982	264.8	(48)	169.0	(30)	120.3	(22)	554.1
1983	251.5	(45)	203.1	(36)	106.3	(19)	560.9
1984	244.1	(42)	264.1	(45)	73.9	(13)	582.1

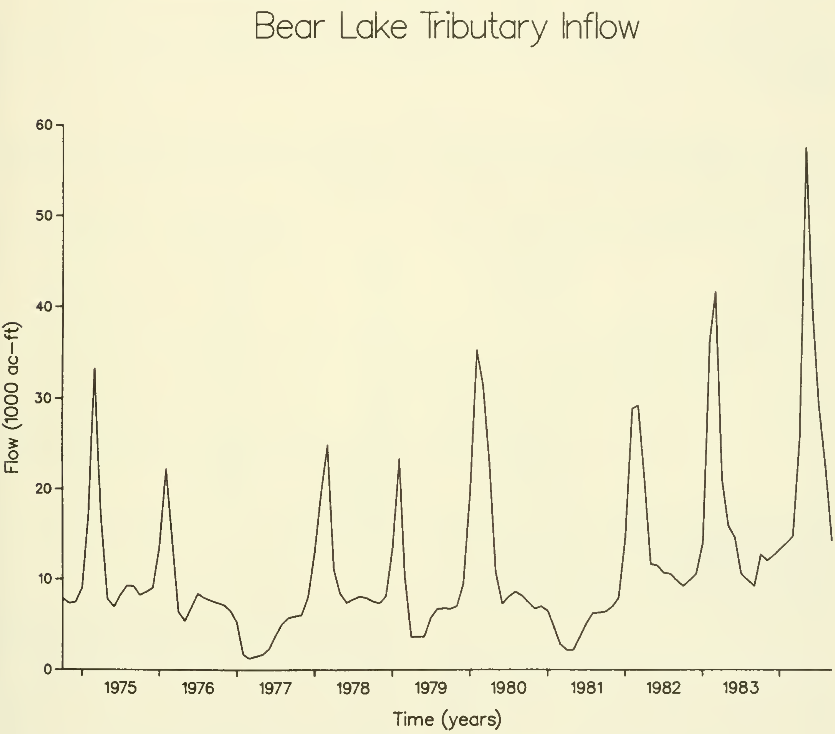

Fig. 4. The flows from the endemic Bear Lake watershed between 1975 and 1984.

BEAR LAKE LIMNOLOGY.—The first reported limnological investigation of Bear Lake was conducted in 1912 by Kemmerer et al. (1923). Since then numerous studies have been made of Bear Lake. An attempt will be made here to summarize the results of limnological investigations on the key physical, chemical, and biological characteristics of the Bear Lake ecosystem.

Bear Lake is oval shaped, about 34 km long and 14 km wide. It has an 81 km shoreline and a surface area of 284 km^2 (Fig. 1). Bear Lake

TABLE 3. The total phosphorus budgets for the major tributaries to Bear Lake for the years 1975 and 1981 to 1984.

Streams	Years (Kg P/Year) 1975[1]	1981[2]	1982[2]	1983[3]	1984[3]	Average percent of total
Lifton (Bear River)	9,982	8,340	18,910	28,362	24,410	67
Swan Creek	495	710	1,860	1,976	2,913	6
Big Creek	1,405	840	1,250	1,716	1,481	6
Fish Haven	125	30	570	—	—	
Little Creek	190	310	600	—	—	
North Eden	920	100	120	—	—	
Falula Spring	780	190	190	—	—	8
South Eden	—	29	40	—	—	
Irrigation return and other streams	640	88	81	2,653	2,320	
Precipitation	1,901	1,860	2,680	3,798	2,551	13
Septic tank leakage	95	260	260	260	260	<1
Total	16,533	12,757	26,561	38,765	33,935	100
Loading (g P/m^2/yr)	.058	.045	.094	.136	.121	

[1]EPA 1975
[2]Lamarra et al. 1984
[3]This study

TABLE 4. The physical and chemical characteristics of Bear Lake, Utah. Chemical characteristics are from Lamarra et al. (1984).

Physical-morphometric characteristics	
Surface area	282 km^2
Mean depth	27 m
Maximum depth	63.4 m
Volume	7.89×10^9 m^3
Mean hydraulic retention time	92 years
Chemical characteristics	
Alkalinity	265 mg as $CaCO_3$/l
Ca++	25 mg Ca++/l
MG++	75 mg Mg++/l
K+	3.1 mg/l
Na+	39.1 mg/l
Cl−	54.2 mg/l
SO_4	19.7 mg/l
Suspended solids	5.0 mg/l
Total dissolved solids	457 mg/l
Volatile suspended solids	1.5 mg/l
Total solids	475 mg/l

TABLE 5. The mean summer areal oxygen deficits (mg O_2/cm^2/day) Chl *a* (μg/l) concentrations in Bear Lake from 1975 to 1984.

Year	Oxygen deficits (mg O_2/cm^2/day)	Chlorophyll *a* (± S. E.) (μg/l)
1975	.026	—
1976	.049	0.41 ± .05
1977	.012	0.30 ± .05
1978	.049	0.66 ± .13
1979	.037	0.62 ± .06
1980	.057	0.78 ± .11
1981	.031	0.39 ± .03
1982	.043	0.59 ± .05
1983	—	0.90 ± .09
1984	.054	0.71 ± .10
Oligotrophic	<.025[(1)]	<.81[(2)]
Mesotrophic	.025–.055	.80–7.4
Eutrophic	>.055	>7.4

[(1)]Hutchinson 1957
[(2)]Vollenweider and Kerekes 1980

has been described as dimictic with a distinct thermocline at 15–17 m. Summer surface temperatures range bewteen 20C and 22C, and hypolimnetic temperatures are usually below 7C. The maximum temperature fluctuations of hypolimnetic water below 50 m have been found to be 2C to 7C. Part of the north and northwest shores of the lake are covered with emergent plants. The remaining shoreline is composed of sand and rock. However, the rocky zone is not extensive, extending only 4 m into the lake. Hypolimnetic sediments are made of marl.

The macrochemical constituents found in Bear Lake are rather unique in their relative abundance (Table 4). Each investigation on Bear Lake has shown that $Mg^{++} > CA^{++} > Na^{+} > K^{+}$ and $HCO_3^{-} > CL^{-} > SO_4^{=} > CO_3^{=}$. Conductivities range between 720 and 680 umhos/cm at 25C and pH between 8.3 and 9.0. The surface oxygen concentrations during the summer in Bear Lake are near saturation, based on temperature and pressure. However, hypolimnetic concentrations were found to be less than 50% of saturation. The mean summer areal oxygen deficits (rate of oxygen loss in the hypolimnion) between 1975 and 1984 can be seen in Table 5.

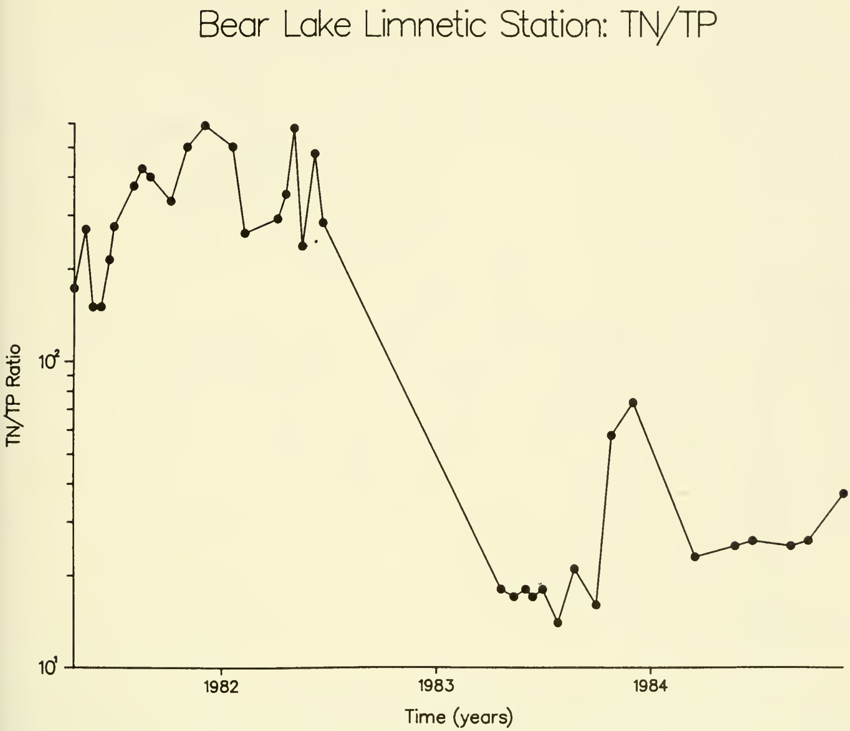

Fig. 5. The total nitrogen to total phosphorus ratio for the surface and 10 m station in Bear Lake between 1981 and 1984. Phosphorus was found to be limiting TN:TP ratio >17, 88% of the time.

An initial analysis of the limnetic nutrient data has indicated that phosphorus appears to be the dominant limiting element in the Bear Lake system (Fig. 5) and therefore the nutrient of most concern. Furthermore, the mean summer total phosphorus concentrations in the epilimnion of Bear Lake have been steadily increasing over the last nine years (Fig. 6).

Because of the uniform shoreline in Bear Lake, rooted plants in the littoral zone of the lake are scarce, therefore relegating the dominant primary production in the lake to the limnetic phytoplankton. The seasonal distribution of the surface (epilimnetic) and subsurface (metalimnetic) phytoplankton biomass can be seen in Figure 7. These data indicate that during the summer months the highest density of phytoplankton occurs between 20 and 30 m below the surface (metalimnetic). In addition, the average summer surface chlorophyll *a* concentrations for 1976 through 1984 are provided in Table 5. Although these data are not representative of the highest algal densities, they do provide a historical perspective of water quality changes within the surface waters of Bear Lake.

Discussion

The limnological conditions present in Bear Lake over the last decade provides some interesting insights into the temporal dynamics of this lake ecosystem. The algal biomass in the lake (expressed as a spring-summer average for chlorophyll *a*) has increased in concentration since 1976, reaching a maximum in 1983 and declining slightly the following year

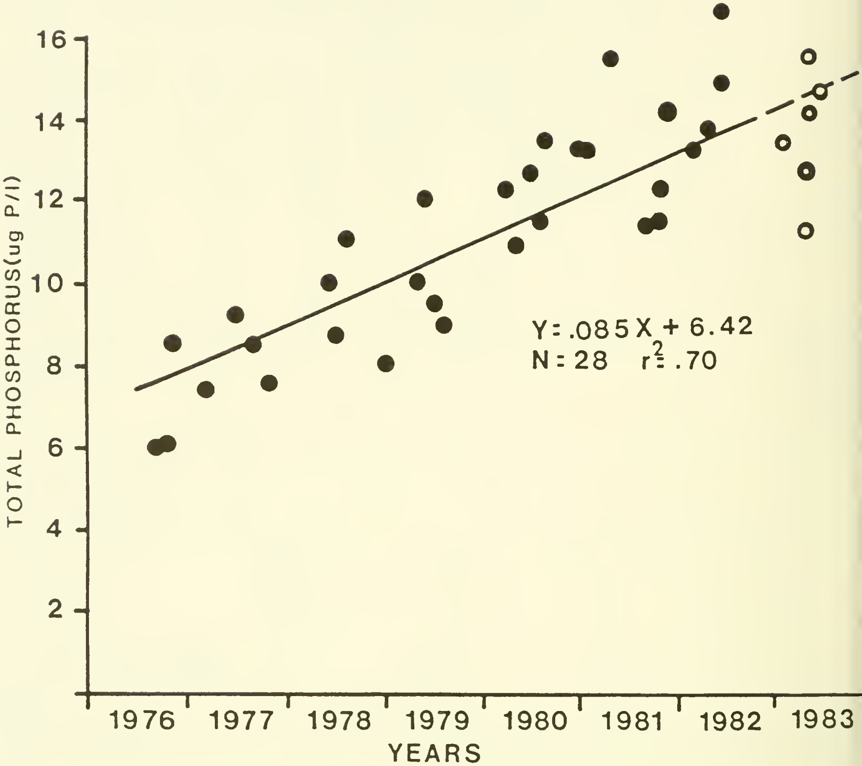

Fig. 6. The mean summer months (April–September) total phosphorus concentrations from the epilimnion of Bear Lake. Sources of the data are from Lamarra et al. 1984.

(Table 5). In a similar manner, areal oxygen deficits (Table 4) and phosphorus loading (Table 2) have demonstrated a year-to-year fluctuation.

The concept of a trophic classification for lake ecosystems has long been recognized. Early studies investigated the quality of plankton and have been summarized by Rawson (1956). More recently, trophic state has been defined by nutrient loading (Vollenweider 1976), complex ecosystem models (Simon and Lam 1980, Ditoro and Matystik 1980), and the interrelationships of a variety of parameters (Porcella 1980). A coarse resolution technique used by Carlson (1977) resulted in using single but interrelated parameters. Total phosphorus, chlorophyll *a*, and Secchi disk transparency have been shown to provide an excellent basis for a trophic state index (TSI). However, because of the presence of $CaCO_3$ precipitates in Bear Lake and its effect upon phosphorus availability, Chl *a* was determined to be the most representative parameter for a TSI calculation. A comparison has therefore been made in Table 6 between the Chl *a* TSI value, areal phosphorus loadings (g P/m^2/year), and areal hypolimnetic oxygen deficits (mg O_2/cm^2/day). In each case the static (TSI), dynamic (areal oxygen deficits), and predictive (areal phosphorus loadings) trophic state classifications indicate that Bear Lake is upper olig-

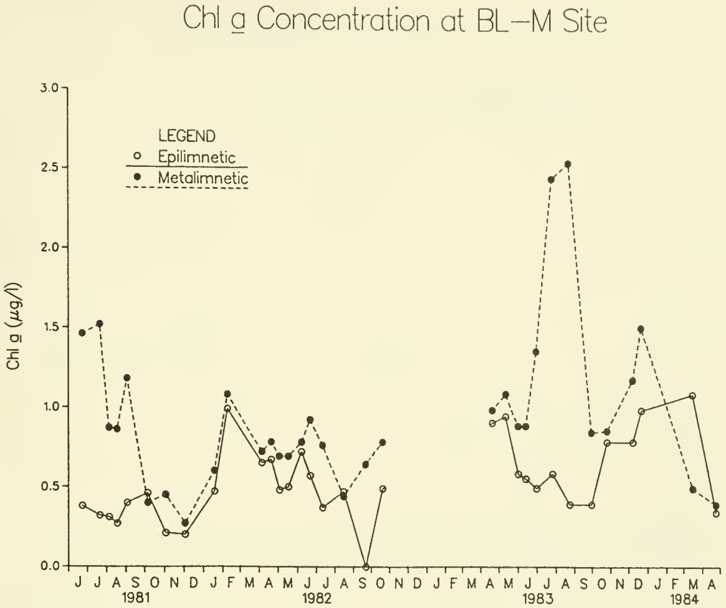

Fig. 7. The temporal distribution of chlorophyll *a* in the epilimnion (surface and 10 m) and metalimnion (20 and 30 m) in Bear Lake, Utah-Idaho.

TABLE 6. The estimated TSI values (Carlson 1977) for chlorophyll *a*, the areal oxygen deficits (mg O_2/cm^2/day), and the total phosphorus areal loadings (g P/m^2/yr) for Bear Lake between 1975 and 1984.

I. TSI parameter (chlorophyll *a* μg/l)	N = 140	TSI values
Average (1975–1984)	0.60	29
Range	.19–3.0	14–45
Oligotrophic[1]	<.80	<30
Mesotrophic	.80–7.4	30–60
Eutrophic	>7.4	>60
II. Areal oxygen deficits (mgO_2/cm^2/day)		**N = 9**
Average (1975–1984)		.040
Range		.012–.057
Oligotrophic[2]		<.025
Mesotrophic		.025–.055
Eutrophic		>.055
III. Areal phosphorus loading (g P/m^2/yr)		**N = 5**
Average 1975 (1981–1984)		.090
Range		.058–.136
Oligotrophic[3]		<.07
Mesotrophic		.07–.15
Eutrophic		>.15

[1]Carlson 1977
[2]Hutchinson 1957
[3]Vollenweider 1976

otrophic to strongly mesotrophic. Because Bear Lake has been previously classified as oligotrophic (Kemmerer et al. 1923), the driving factors for the observed trophic changes need to be elucidated. The limnological trends presently observed in the lake may be the result of increased human activity within the basin, increases in the hydrologic inputs, or a combination of these factors. Comprehensive sets of water quality data for the Bear River, Bear Lake watersheds, and Bear Lake do not exist prior to 1975. As an alternative to a historical data base, inferences to previous water quality conditions in Bear Lake can be made from the extensive hydrological data available. Based upon the data presented here, a series of regression equations were produced that indicated the watershed loadings of phosphorus and inlake water quality parameters (summer chl *a* and oxygen deficits) were significantly related to mass flows from the watersheds (Table 7). Based upon these statistical relationships and the historical flow data, hydrologic and nutrient budgets were developed for the recent history

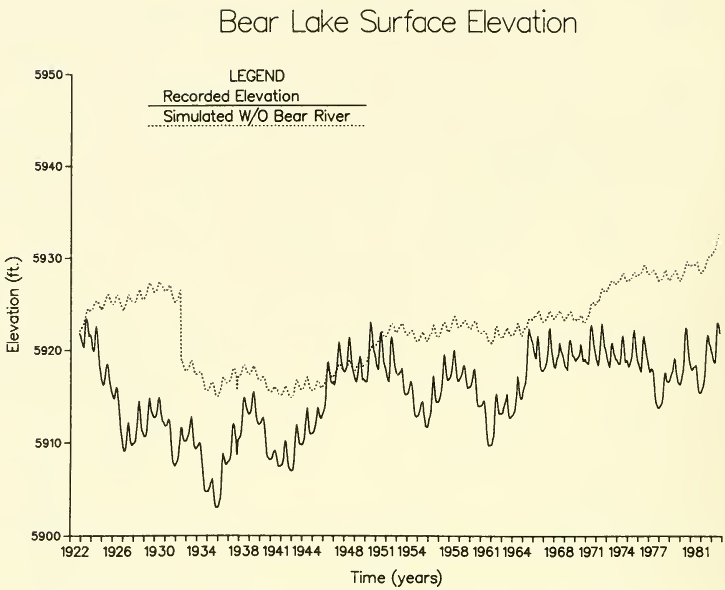

Fig. 8. The simulated elevations in Bear Lake without the Bear River and the natural elevations with the operation of the Bear River storage system between 1924 and 1984.

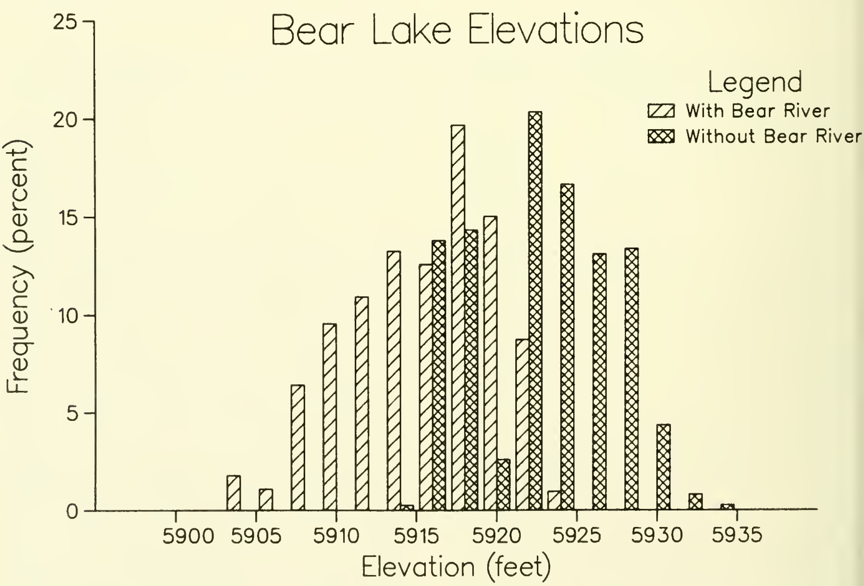

Fig. 9. A frequency distribution of monthly Bear Lake elevations (1924 to 1984), with a simulated watershed excluding the Bear River and actual elevations with the Bear River.

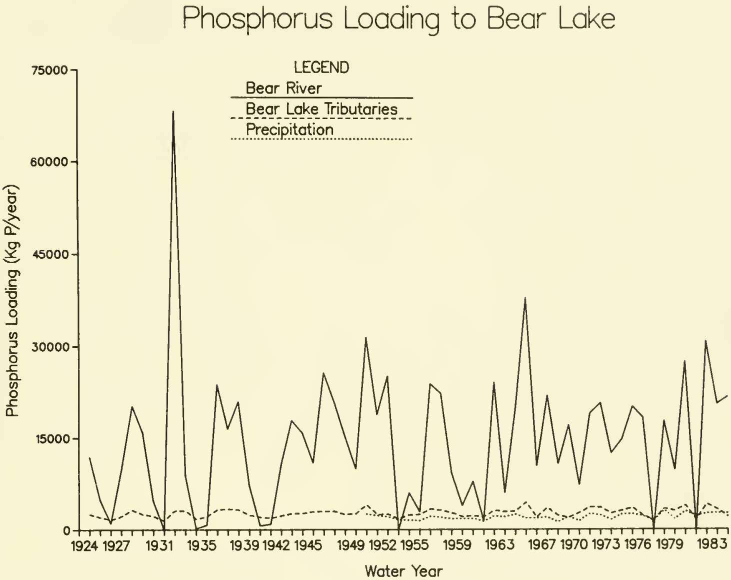

Fig. 10. The estimated mass (kg P/year) of phosphorus entering the Bear Lake system between 1924 and 1984.

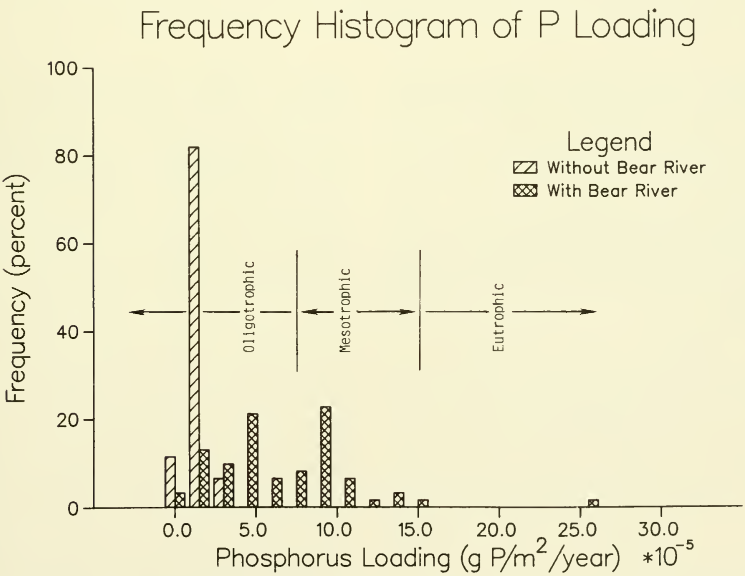

Fig. 11. The frequency distribution of areal total phosphorus loading (g P/m^2/yr) for Bear Lake with and without the Bear River for the period 1924–1984.

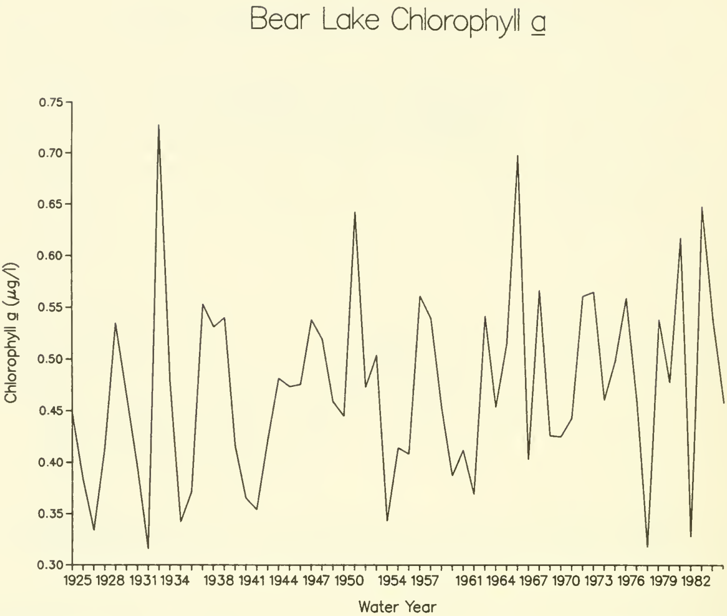

Fig. 12. The historical distribution of mean summer chlorophyll *a* concentrations as simulated from the empirical relationships developed from the years 1975 through 1984.

(1923–present) in Bear Lake with and without Bear River inflows. The major assumption made in this analysis was that the historical water quality in the Bear River had not significantly changed and is similar to the period 1975–1984.

The hydrologic budget for Bear Lake was developed using all sources and losses on a mass balance basis. Input data for equation (1) was obtained from Utah Power and Light Company.

$$\triangle S = (I - O) - S \qquad (1)$$

where: $\triangle S$ = Annual change in Bear Lake storage (ac-ft/year)
I = Rainbow canal inflow (ac-ft/year)
O = Outlet canal flow (ac-ft/year)
S = Actual Bear Lake storage from elevation capacity curves (ac-ft/year)

The results of this analysis, with and without the Bear River inflows can be seen in Figure 8. The data indicate that the simulated elevations in Bear Lake without the river were higher (except for the years 1944–1950) than the lake elevations with the river inflow-outflow manipulations. The estimated elevations of the lake indicated that the threshold of 5,927.0 ft between Bear Lake and the marsh complex would have been exceeded about 24% of the time during the last 60 years (Fig. 9), providing a direct connection between the shallow marsh in the northern valley and the lake to the south. In addition, the simulation indicates that during the 1970s the lake would have had a steady increase in elevation above 5,924 ft to a high elevation of 5,935 ft in 1984. This increase in lake elevation would inundate the confluence of the Bear River and the Bear Lake valley, thus naturally adding a 7,000 km^2 watershed to the Bear Lake drainage.

During the same time period simulated in the hydrologic budgets, the annual phosphorus loading (kg/year) by source was estimated (Fig. 10). It appears that about 60% of the historical loading to the lake can be attributed

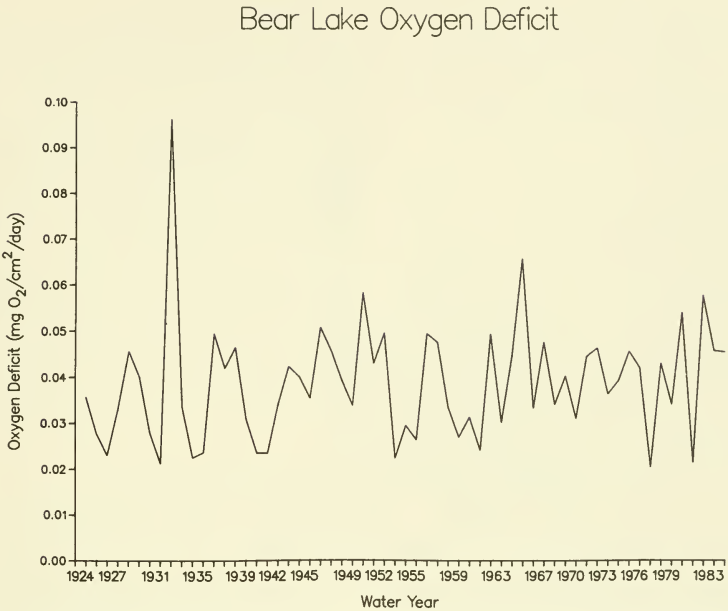

Fig. 13. The historical distribution of mean summer areal oxygen deficits (mg O_2/cm^2/day) as simulated from the empirical relationships developed from the years 1975 through 1984.

to the Bear River, and in only 10 years of the last 60 has the endemic watershed produced more phosphorus loading than the Bear River. A frequency analysis of areal phosphorus loadings indicates that with the presence of the Bear River, 58% of the last 60 years the loading could be considered oligotrophic, while 42% could be considered mesotrophic or eutrophic. In contrast, without the Bear River inflows 100% of the annual loadings would be oligotrophic (Fig. 11).

In a similar manner, the simulation of the historical chlorophyll *a* and areal oxygen deficits (Fig. 12, 13) with the presence of the Bear River demonstrates the importance of this water source in modifying the Bear Lake environment. Frequency histograms for both parameters (Fig. 14, 15) demonstrate patterns similar to those expressed by areal phosphorus loadings, indications that the Bear River may have shifted the trophic state of Bear Lake from oligotrophic to mesotrophic.

The Bear Lake ecosystem is a unique environment. Because of its isolation for more than 8,000 years, the biological community has evolved into a simple, coexisting trophic structure, with four endemic species of fish. The uniqueness of the Bear Lake community lies in the adaptations of the organisms to one another and the importance of the endemic fish to the overall trophic structure. For example, the cisco is a dominant food item of the large predators and is, itself a planktivore, feeding exclusively on zooplankton within the metalimnion during summer stratification. In turn, the zooplankton community has few large cladocerans, with its structure dominated by a large *Epischura* sp. This organism has adapted a swift predatory escape mechanism. Because the effect of water quality changes upon these species is unknown, defining the driving factors and their degree of impact upon changes in water quality may provide management alternatives for this ecosystem.

The results of this preliminary investigation have inferred the historical impacts of the Bear River inflows upon the limnological con-

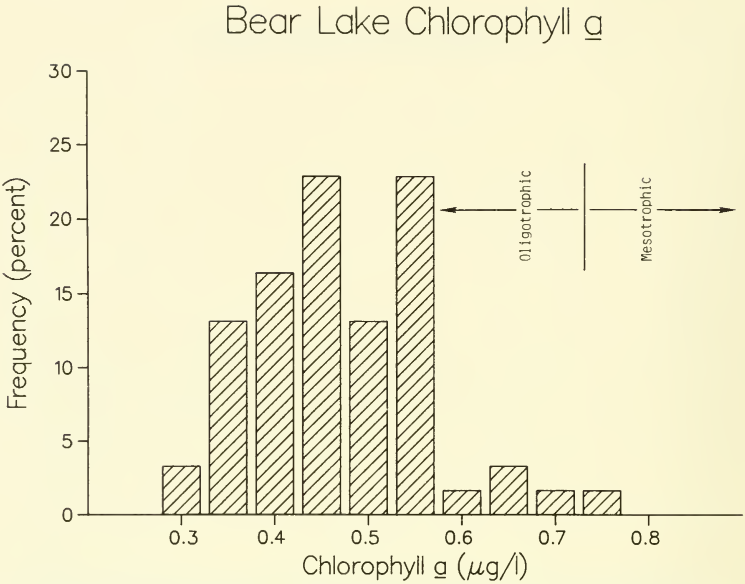

Fig. 14. A frequency histogram of the simulated mean summer chl *a* concentrations (µg/l) for the years 1924 through 1984.

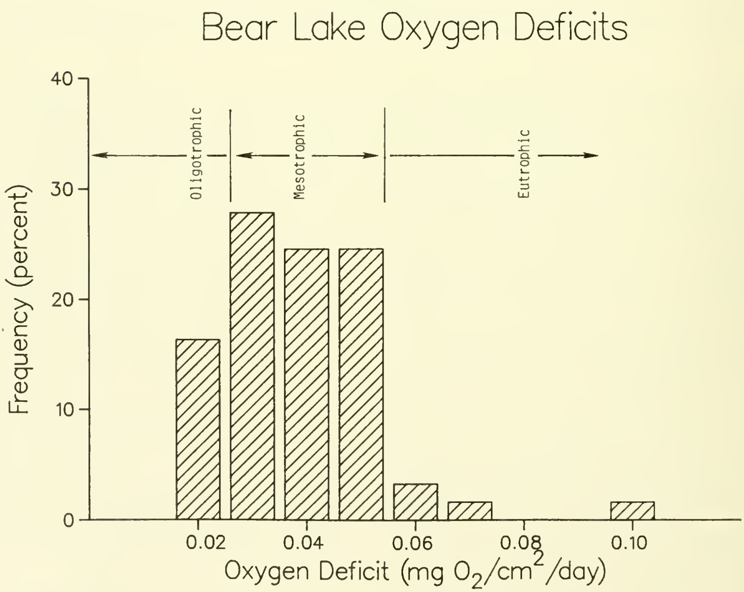

Fig. 15. A frequency histogram of the simulated mean summer areal deficits (mg O_2/cm^2/day) for the years 1924 through 1984.

ditions in Bear Lake, based upon 9 years of empirical limnological data and 60 years of historical flows. This impact has been extensive. In addition, the future human developments of the Bear Lake basin will only increase the nutrient export from the watershed to the lake environment. Mitigation measures that directly address sources of nitrogen and phosphorus within the watersheds must be developed. Increased eutrophication may result in the loss of several if not all of the endemic species. In a similar manner, the investigation of alternative hydrologic storage of the Bear River as it relates to Bear Lake seems advisable. The development of 100,000 ac-ft of storage above Bear Lake may reduce previously described oxygen deficits and cut the phosphorus loading by 7,000 kg/year.

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