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Hydrology of the Bear Lake Basin, Utah

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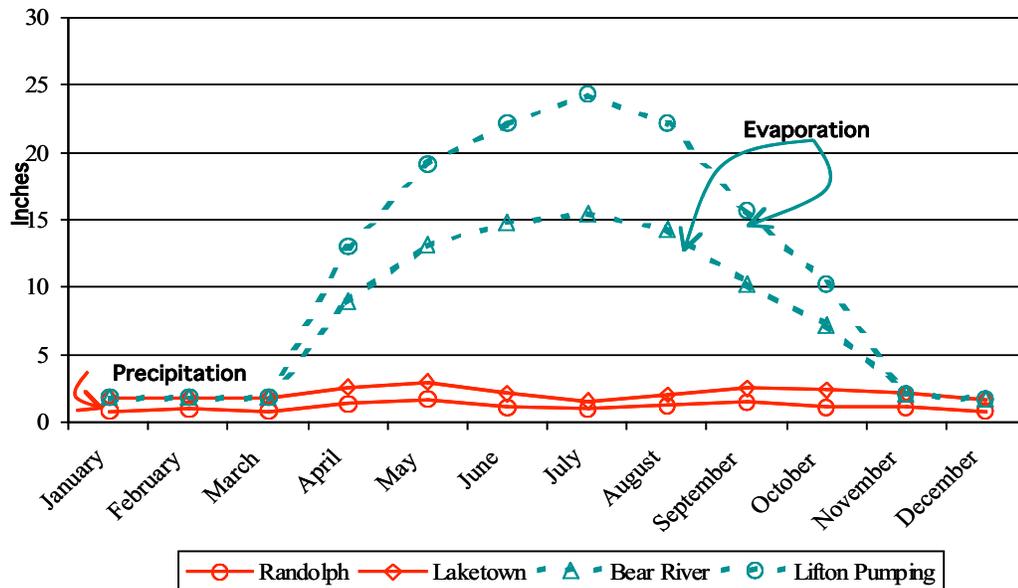
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Graph 3. Average 25-Year Monthly Precipitation and Evaporation in the Bear River Basin 1975-2000. Red line indicates precipitation collected at Randolph and Laketown climate stations and the green lines represent pan evaporation from the Bear River, ID and the Lifton Pumping climate stations. (Western Regional Climate Center, 2003).

HYDROLOGY

Bear Lake's natural watershed is made up of relatively low mountains covered with sagebrush at lower elevations and southern exposures and fir-aspen forests at higher elevations and northern exposures. The basin is traversed by the Bear River that begins high in the Unita Mountains and flows through Utah, Idaho, and Wyoming before feeding the Great Salt Lake. The Bear River is the major river in the watershed but does not directly feed Bear Lake. The key inflow tributaries for the Lake are North and South Eden Creeks from the east, Fish Haven, St. Charles, Cheney, and Swan Creeks from the west, and Spring and Big Creek from the south. The outflow is a canal through Dingle Marsh and into the Bear River. Woodruff Narrows Reservoir is a major impoundment of the Bear River just

downstream from Evanston, Wyoming, and there are small upstream impoundments on Birch Creek and both Eden Creeks (Judd, 1997).

Bear Lake is stratified in summer-spring where lighter water overlies denser water. During the winter months the mixing processes of winds and surface cooling break down the layers and the lake freezes over. Bear Lake does not completely freeze over every year but typically three out of five years. In its stratified state; Bear Lake forms a distinct thermocline with an upper layer of warmer water with temperatures ranging between 58-72°F and a lower layer of colder water between 35-42°F. The temperature usually drops over just a few feet at a depth of 45-55 feet from the surface.

| Bear Lake Water Column Profiles | | | |
|--|-------------------|-----|--------------------------------|
| Depth (feet) | Temperature (° F) | pH | Dissolved O ₂ (ppm) |
| 16 | 59.9 | 8.8 | 7.8 |
| 49 | 59.5 | 8.8 | 7.9 |
| 82 | 46.8 | 8.6 | 8.1 |
| 115 | 41.5 | 8.5 | 7.1 |
| 148 | 41.0 | 8.3 | 6.2 |
| 180 | 40.8 | 8.3 | 5.4 |

Table 7. Bear Lake Water Column Profiles (Judd, 1997).

Table 7 details the average annual temperature, pH, and dissolved oxygen levels as they are in the water column of the Lake. The amount of dissolved oxygen present in the Bear Lake water column declines during the summer months as water temperatures rise. The late summer temperature and dissolved oxygen profiles represent the lake's most stressed period (Judd, 1997). More than 5 parts oxygen per million parts water is considered healthy; below 3 parts oxygen per million is generally stressful to aquatic organisms. Adequate dissolved oxygen is critical to most aquatic organisms and is one of the more important indicators of environmental health. Conductivity is a measure of the water's ability to carry an electrical current. The measurement is used in fresh water analyses to obtain a rapid estimate of dissolved solids or salts content of a water sample, a pristine

mountain stream may have a conductivity range from 15-35 $\mu\text{mhos/cm}$ whereas normal seawater will range between 50,000-60,000 $\mu\text{mhos/cm}$. Bear Lake generally carries a conductivity measure between 684-690 $\mu\text{mhos/cm}$ (Judd, 1997). This reading has remained stable or only slightly increased since early investigations in the 1940's (Hassler, 1960).

The pH is a measure of the activity of hydrogen ions (H^+) in the water and is the measure used to determine its acidity or alkalinity. The pH levels in Bear Lake have remained at a consistent average of 8.0 (slightly alkaline) since Hazzard investigated them in 1934 (Sigler, 1972). This is a direct result of the high amounts of limestone and dolostone found in the area. The Bear Lake fault, under the eastern side of the lake, acts as a conduit for groundwater with numerous springs coming to the surface either on land or in the lake itself. These rocks weather by dissolution, producing many sinkholes, caves and springs. As a result, much of the water in streams entering Bear Lake originates as springs in the Bear River Range. (Kaiser, 1972).



Bear Lake Over Garden City

Photo from: <http://community.webshots.com/user/twinaterau>

Bear Lake is often called the Caribbean of the Rockies for its intense turquoise-blue water. The unique color is due to the reflection of the limestone deposits suspended in the lake.

Figure 9, modified from Lamarra (1979), shows the local watershed boundaries as they were defined in 1979.

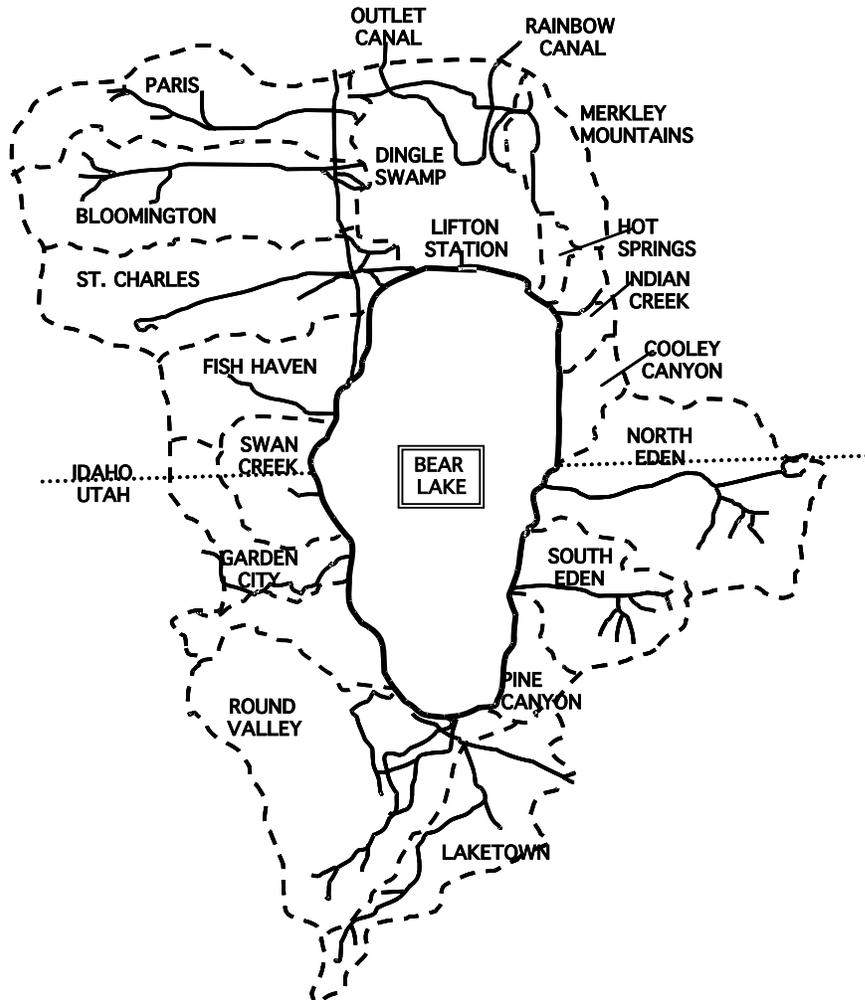


Figure 9: Watershed Boundaries and Stream Locations (Modified from Lamarra, 1979).

The 4 major and 3 minor tributaries to the lake, excluding the Bear River, drain a 228 square mile watershed. An average of 66,000 acre-feet of water per year enters the lake from this watershed. Historically, much of this water, over 55 inches on average, is evaporated during the summer months.

The lake and drainage characteristics are given in table 8.

| Lake and Drainage Characteristics | | | |
|--|-----------------------------|--|--|
| | Surface Area | 112 miles square | |
| | Shoreline | 48 miles | |
| | Maximum Depth | 208 feet | |
| | Mean Depth | 94 feet | |
| | Lake Elevation | 5,924 feet | |
| | Volume | 6,550,871 acre-feet | |
| | Vertical Fluctuation | 10.5 feet | |
| Primary Inflow | | | |
| | Name | Drainage Area (square miles) | Mean Annual Flow (cubic feet / sec) |
| | Big Creek, Utah | 95.0 | 19.0 |
| | Indian Creek, ID | 4.5 | .21 |
| | North Eden Canyon, Utah | 53.0 | 11.0 |
| | South Eden, Utah | 23.0 | 4.8 |
| | Swan Creek, Utah | 4.0 | 18.0 |
| | Fish Haven Creek, Idaho | 12.0 | 3.4 |
| | Little Creek, Idaho | 36.0 | 7.1 |
| | Bear River Water | 104.0 | 26.5 |
| | Totals | 332.0 | 90.0 |
| Outlet Channel | | | |
| | Outlet Channel (Bear River) | 398.0 | 89.0 |
| Evaporation | | | |
| | Annual Average | 55.15 inches / year or 5% of total mean volume | |

Table 8. Lake and Drainage Characteristics (Lamarra, 1979).

INFLOWS

Endemic inflows are those that have not been spatially altered by human influence. In the Bear Lake drainage endemic flows consist of 4 perennial streams, 2 major seasonal streams, and numerous near shore springs and ephemeral inputs. The perennial streams, located primarily on the western shore, are Big Sprig Creek, Swan Creek, Fish Haven Creek and St. Charles Creek. The seasonal or snowmelt driven streams are located on the east shore and are North Eden and South Eden Creeks. During drought cycles and low precipitation years all streams, except Swan

Creek, dry up or are dewatered for irrigation purposes. Swan Creek is protected as a culinary water supply and, due to its relatively high flows and short length, is rarely dewatered.

The first week of June typically has the highest rates of runoff. Stream flows on the Bear Lake tributaries in 2004, one of the driest years in this watershed, during the spring runoff period were:

Swan Creek 73.0 cubic feet/second

St Charles Creek 39.9 cubic feet/second

Big Spring Creek 17.2 cubic feet/second

Fish Haven Creek 13.5 cubic feet/second

The total tributary input was 164 cubic feet/second. During this year Bear Lake's elevation rose 1.5 feet during spring runoff (USGS, 2006).

In comparison 1997 was a wetter year and stream flow during peak runoff were:

Swan Creek 267.0 cubic feet/second

St Charles Creek 179.0 cubic feet/second

Big Spring Creek 98.2 cubic feet/second

Fish Haven Creek 77.3 cubic feet/second

Total tributary input was 638 cubic feet/second and that year the lake rose 7.5 feet during spring runoff.

The inflow estimates for 1983 are closer to the average for the Bear Lake watershed. In that year the peak runoff per stream were:

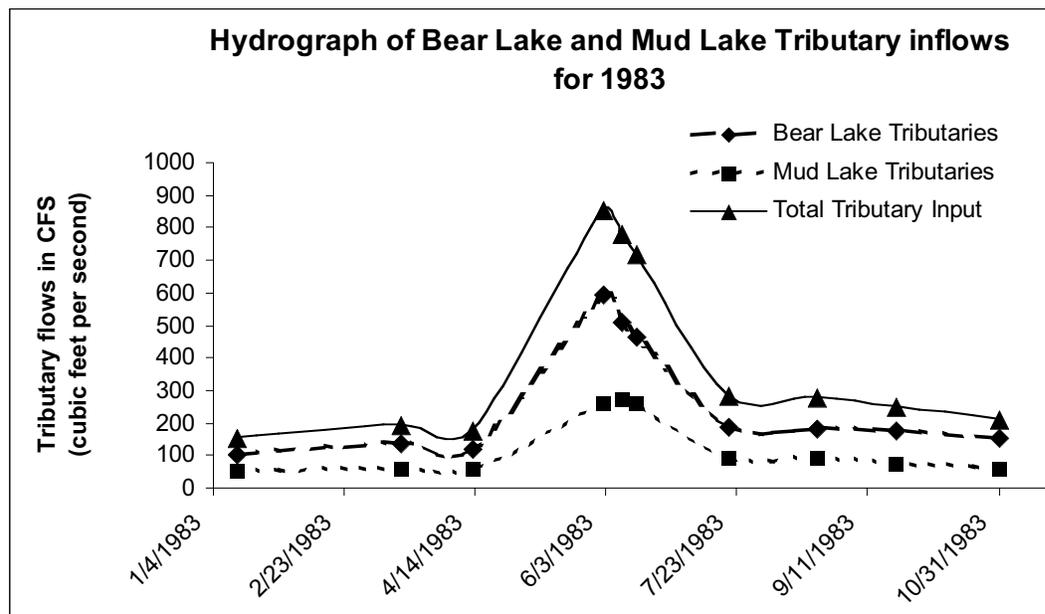
Swan Creek 249.0 cubic feet/second

St. Charles Creek 129.3 cubic feet/second

Big Spring Creek 93.9 cubic feet/second

Fish Haven Creek 82.9 cubic feet/second

Total tributary input for this typical year was 583 cubic feet/second and the lake rose 4.5 feet between April and July (Lamarra, 1986).



Graph 4. Hydrograph of Inflows for 1983 (Recreated from Lamarra, 1986).

Water flowing in Bear River is diverted to Bear Lake for storage. The point of diversion is located approximately 5 miles south of Montpelier, Idaho, at Stewart Dam. At Stewart Dam, most of the flow is diverted south into a canal and has an average annual flow of 26.5 cubic feet per second. Water is returned to the river below the Bear Lake outlet with an annual average of 776.9 cubic feet per second due to inputs from other tributaries. Graph 4 depicts the flows for the inflow tributaries of Bear Lake and Mud Lake from January to November of 1983. Flows are measured at two permanent gaging stations, one near Pescadero, Idaho below the Bear Lake outlet and the other above Alexander Reservoir, Idaho.

LAKE SEDIMENT CHARACTERISTICS

Sediments deposited in Bear Lake region are largely composed of calcium carbonate, calcium, or limestone. These glacial sediments have a dominance of shale and sandstone that were formed by the compaction of the quartz-rich mineral grains that surround the lake. The lake bottom consists primarily of marl, a granular

material composed largely of calcium carbonate and limestone fragments that contain varying amounts of organic matter. Marl sediment deposits are largely decayed organic material and minerals characteristic of Bear River drainage geology. Organic matter accumulation is higher when nutrient levels are increased. Water from the Bear Lake watershed is naturally low in organically available nutrients usable for organic growth and out-of-basin nutrient inputs can often increase productivity within the Lake itself (Wurtsbaugh, 1998).

Changes in sedimentation rates and nutrient composition have been recognized since the diversion of Bear River water back into Bear Lake in the early 1900's. Smoak and Swarzenski (2004) analyzed shallow cores of Bear Lake sediment to identify changes in bulk sediment and nutrient content over time, specifically the last 100 years. Sediment accumulation and nutrient concentration has increased markedly in the last century. The mass accumulation rates for sediment between 1866 and 1919 were 18 mg/cm²/year; during the period from 1991-1998 they were 90 mg/cm²/year. Nutrient analysis indicated increases of nitrogen (6-8 fold), phosphorus (3-8 fold), inorganic carbon (4-8 fold), and organic carbon (5-8 fold) for the same period of time.

The Bear River water enters through a canal, first at Mud Lake and then Bear Lake. The Bear River carries a large sediment load as it progresses through easily eroded rock upstream of Bear Lake Valley. This sediment falls out rapidly when the speed of water in the diversion channel slows upon reaching the swamp. The interactions of the waters with the swamp allows for a significant amount of nutrients to be taken from the Bear River waters and consumed in the marsh before it reaches the lake (USGS, 2001).

The mixed lake and river water leaves Bear Lake with the activation of the Lifton Pumping Station. An earthen causeway separates Bear Lake from Mud Lake. PacifiCorp controls the flow and structures located in the causeway and on May 6, 1993, the structure washed out. Mud Lake was higher than Bear Lake and materials from the causeway and silt from the adjacent Mud Lake washed into Bear

Lake. PacifiCorp has since designed and constructed a new control structure. The failure of the causeway prompted the Ecosystems Research Institute of Logan to investigate the water quality impacts of the building of the new structure. Total suspended solids and turbidity data was collected for eleven consecutive weeks at three open water stations during 1997. Data collected during this investigation have indicated that 75% of the sediment was removed by the marsh prior to its entrance into Bear Lake (Lamarra, 1997).

WATER QUALITY

The completion of the pumping station inevitably modified the lake's physical and chemical characteristics. The water quality discussed in this section is based on conditions as they have existed since the pumping station began operating in 1918.

The water flowing into Bear Lake from both its Utah and Idaho tributaries were in compliance with state mandates for designated uses during their last review. The United States Environmental Protection Agency lists the tributaries of Swan Creek, Laketown Creek, Big Spring Creek, North Eden and South Eden as monitored sites that are meeting water quality standards as designated by the state of Utah. Each of the above water bodies is listed with "good" water status, indicating that all designated uses are being met (USEPA, 2002).

The tributaries designated uses, as defined by the State of Utah, are for recreational activities; agricultural uses, such as irrigation and stock watering; and for cold-water aquatic species. Swan Creek has an additional designation as a culinary water supply for recreational contact activities and for cold-water aquatic species (Division of Administrative Rules, 2006).

The waters within Bear Lake are also in compliance with the state of Utah beneficial use designation. Designations for these waters are for primary contact recreation, secondary recreation contact, coldwater fish and aquatic life, and for irrigation and stock watering (Division of Administrative Rules, 2006). Water chemistry according

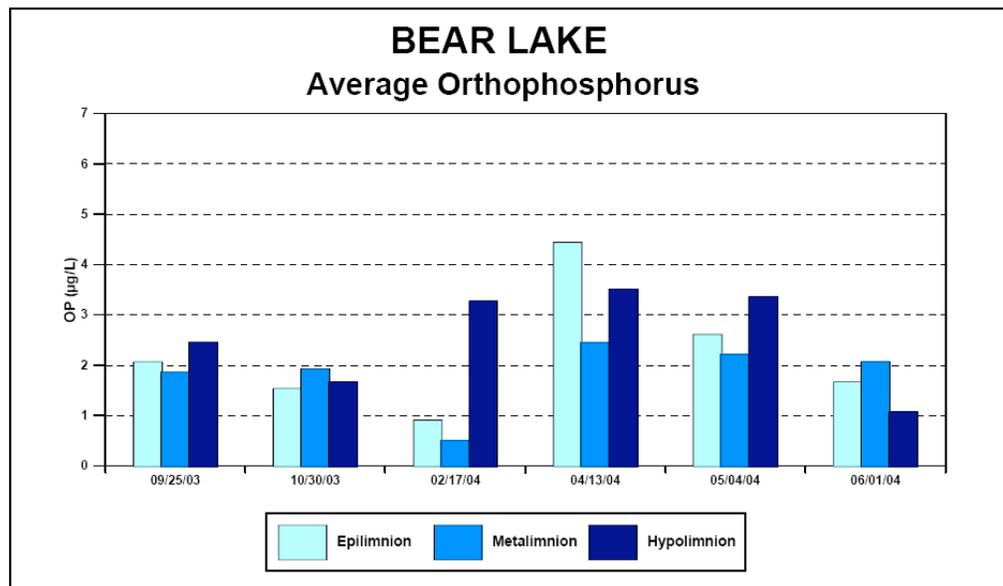
to the Judd (1997) and recognized by the Utah Division of Water Quality is outlined in table 9. The measurements are annual averages for the given years.

| Water Quality Data | | | | |
|-------------------------------|---------|--------|---------|--------|
| Parameter | 1993 | | 1995 | |
| | Surface | Column | Surface | Column |
| Transparency (feet) | 15.4 | | 14.8 | |
| Total Phosphorus (ug/L) | 20.0 | 18.0 | 5.0 | 6.0 |
| Total Suspended Solids (mg/L) | 1.7 | | 2.0 | |
| Total Hardiness (mg/L) | | 289.0 | 294.0 | |
| Total Alkalinity (mg/L) | | 247.0 | 241.0 | |
| Ammonia (mg/L) | | .03 | | .03 |
| Nitrate/Nitrite (mg/L) | | .02 | | .01 |

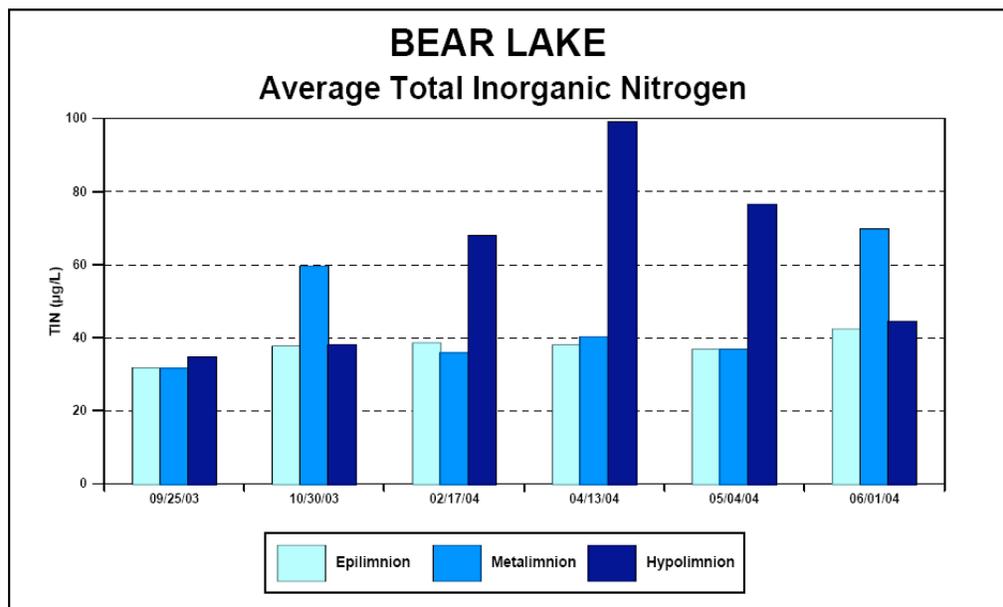
Table 9. Water Quality Data for Bear Lake in Years 1993 and 1995 as Determined in Utah's Lakes and Reservoirs Classification and Inventory (Judd, 1997).

The Clean Lakes Program, established in 1972 as section 314 of the Federal Water Pollution Control Act, sampled Bear Lake in 1982 to set a baseline assessment for future inventory and classification. Monitoring stations are available at the North Beach Idaho State Park and by Garden City for ongoing data sampling. These original studies determined that phosphorus, potassium, and nitrogen, although sparse in the shallow water, are adequate enough in the deep-water to support varied plant growth.

Specific studies designed to determine which nutrient limits growth of algae indicated that phosphorus and/or nitrogen almost always were the limiting factors. Sigler (1972) found nitrogen to be limiting more than half the time, whereas Birdsey Jr. (1989) suggests that phosphorus limited algal growth more often. In 2004, however, the Ecosystems Research Institute conducted a water chemistry analysis that showed relatively low levels of nitrogen and phosphorous throughout the year. Graphs 5 and 6 on the following page illustrate this trend.



Graph 5. Phosphorus Concentrations for Bear Lake 2003-2004. Epilimnion= shallow water, metalimnion=mid water and hypolimnion= deep water. Orthophosphorus is phosphorus that is usable by biological organisms (Ecosystem Research Institute, 2004).



Graph 6. Nitrogen Concentrations for Bear Lake 2003-2004. Epilimnion= shallow water, metalimnion=mid water and hypolimnion= deep water (Ecosystem Research Institute, 2004).

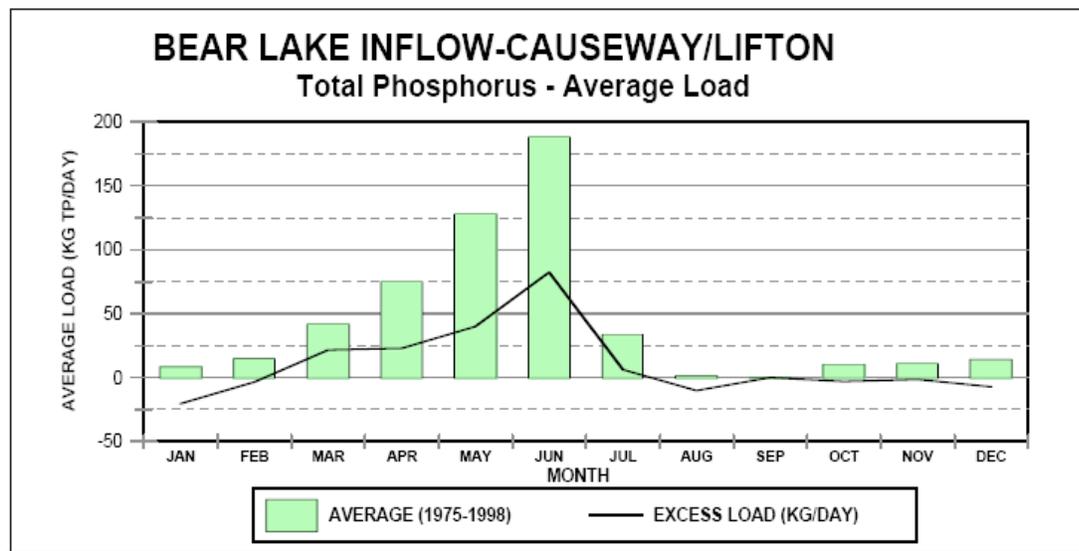
Nitrogen to phosphorus ratios indicated that the lake is likely to be phosphorous limited. The Ecosystem Research Center further determined there is significant nutrient loading by Bear River water as it enters the Lake through the Marsh. Smoak and Swarzenki (2004) claim that despite increased nutrient loading since the diversion of Bear River waters, chemistry does not appear to have changed significantly likely due to binding of nutrients to calcium in the water column and subsequent precipitation to and storage in sediment. The amount of biologically available nutrients is not associated with increased input of total nutrients.

The Ecosystems Research Institute (2005) produced a data summary, a report listing the Total Mass Daily Load (TMDL), and a report of the water quality for the Bear River drainage in Idaho. An excerpt from that report describes the conditions of concern for Bear River waters as they enter into Bear Lake proper:

“the outflowing water quality at the Causeway station exceeds the TMDL criteria for total phosphorus in two of the four hydrologic periods. Because these periods occur during the filling cycle for the lake, these exceedances represent a significant source of phosphorus to Bear Lake. The largest exceedance occurs during upper basin runoff (51 kg TP/day) followed by lower basin runoff (22 kg TP/day). In the summer and winter base flow periods, no excess phosphorus enters Bear Lake. The total suspended solids mass does not exceed the TMDL limits established at the Causeway station.”

The Bear River itself, as it enters the upper basin from Wyoming, is currently classified for recreational and wildlife uses and under this classification the river meets standards. For the parameters of total dissolved solids, turbidity, hardness, iron and manganese, the quality of the Bear River in Utah exceeds drinking water supply standards (Division of Water Resources, 2000).

Graph 7 and Table 10 express visually the levels of phosphorus loading in the marsh during inflow and outflow from the lake. Excess loadings are based upon a criterion of 0.05 mg TP/l and 60 mg TSS/l during runoff season and 35 mg TSS/l during base flows. A total of 276 data points are represented in these figures.



Graph 7. Distribution of Total Phosphorus Loads by Month and Excess Total Phosphorus for all Inflows into Bear Lake (Ecosystems Research Institute, 2005).

Non-point pollution sources include the following: grazing, urban runoff, agricultural runoff, and feedlots. Natural inflows to the reservoir have deteriorated since the valley has been used for intensive agriculture. In addition, winter feedlots for livestock have destroyed streams that once were spawning grounds for cutthroat trout. The valley floor is composed of lake deposits in the form of layers of permeable sand and impermeable clay, which drain agricultural runoff directly into the lake rather than allow them to disperse. There are no discharging point sources of pollution in the immediate watershed. However, there are point source discharges into the Bear River prior to its diversion into the lake. One major discharger is the Evanston Wastewater Treatment Plant in Evanston, Wyoming (Judd, 1997).

| Month | Average Concentration mg/L | Average Mass (kg/day) | Excess Mass over Criteria (kg/day) |
|-------------------------------|----------------------------|-----------------------|------------------------------------|
| Total Phosphorus | | | |
| January | 0.015 | 8.16 | -20.60 |
| February | 0.061 | 14.70 | -3.51 |
| March | 0.073 | 41.70 | 21.50 |
| April | 0.061 | 74.90 | 22.90 |
| May | 0.067 | 128.00 | 39.90 |
| June | 0.072 | 188.00 | 82.40 |
| July | 0.044 | 33.70 | 6.12 |
| August | 0.029 | 1.15 | -10.30 |
| September | 0.051 | 0.001 | 0.00 |
| October | 0.043 | 10.40 | -3.04 |
| November | 0.040 | 10.80 | -1.57 |
| December | 0.038 | 14.10 | -7.30 |
| Total Suspended Solids | | | |
| January | 7.74 | 7,880 | -9,470 |
| February | 6.31 | 1,230 | -11,300 |
| March | 30.90 | 16,000 | -6,110 |
| April | 21.40 | 31,400 | -19,000 |
| May | 30.40 | 75,700 | -31,700 |
| June | 23.00 | 64,700 | -52,900 |
| July | 16.70 | 12,500 | -17,400 |
| August | 16.30 | 0.363 | 0 |
| September | 12.40 | 0.3 | 0 |
| October | 12.10 | 6,690 | -5,260 |
| November | 26.10 | 5,910 | -2,740 |
| December | 19.00 | 13,000 | -1,920 |

Table 10. Average (1975-1998) Water Quality Data for Selected Parameters at the Bear Lake Causeway and Lifton Pumping Station. Negative values under heading "Excess mass over Criteria" indicates kg/day lower than threshold criteria (Ecosystem Research Institute, 2005).