# Drought effects on the timing and influent water quality to Barr Lake, Colorado

Curtis Cooper
Department of Soil and Crop Sciences, Colorado State University, Fort Collins 80523-1170.

J.D. Stednick[1]
Department of Forest, Rangeland and Watershed Stewardship, Colorado State University, Fort Collins 80523-1472

David Gilbert
Department of Civil Engineering, Colorado State University, Fort Collins 80523-1372

**Abstract:** Barr Lake is a 45,000 acre-foot irrigation reservoir located near Brighton, Colorado and is filled from the South Platte River. The diversion to Barr Lake is below the metro area and often includes effluent directly from the Denver Metropolitan Wastewater Reclamation District. Upstream water exchanges have resulted in increasing volumes of wastewater effluent in the South Platte River particularly in the winter months. Water quality at Barr Lake has been monitored since 1997. Water quality data comparisons were made between 3 "normal" water years (1997-1999) against 3 drought years (2000-2002). The drought not only influenced the volume of water diverted into Barr Lake, but also the timing of the diversions. During the drought years the reservoir was filled during the late winter flows, rather than the spring flows as in normal years. The drought had minimal effect on the maximum water quality constituent concentrations that occur, mostly in the winter flows. The difference between normal and drought water quality concentrations was the lack of annual dilutional flows, increasing minimum concentrations of water quality constituents. The drought resulted in greater mean concentrations into Barr Lake during the drought years. This observation may need to be considered in drought planning.

## 1. Introduction

In the semi-arid climate of eastern Colorado drought decreases the already limited water resources. The combination of water rights, drought, and water quality leads to a convolution of State laws, Federal laws and private property rights. Since water quality has Federally mandated criteria and water quantity is a State based regulation, there is ample opportunity for conflict, and drought accentuates those issues.

[1] Corresponding Author:
Department of Forest, Rangeland and Watershed Stewardship,
Colorado State University,
Fort Collins, CO 80523-1472
(970) 491-7248
jds@cnr.colostate.edu

Water quality in the United States is regulated by what is collectively termed as the Clean Water Act (CWA) (US Code, 1998). The CWA sets forth national water quality laws that are applicable to all states. However, the US Environmental Protection Agency, oversees the application of the water quality laws by defining criteria and oversight of state entities. In Colorado, the Water Quality Control Division (WQCD) of the Colorado Department of Public Health and Environment is responsible for the standards development and enforcement that meet the EPA criteria. However, the WQCD has little influence in water quantity issues.

In water quality monitoring and planning, winter low flows are often the time of the highest concentrations that occur in snow dominated hydrologic systems. Whereas the late spring and early summer months are the time when dilution occurs due to greater volumes of discharge. Droughts often modify the hydrograph so that spring flows are not so dilute, and this is compounded by human modifications to the hydrograph. Dams and other impoundments are the keys structures for these hydrograph modifications. Barr Lake is no exception; often the South Platte River at the point of diversion is essentially dry, so that the water rights are filled. .

It was known that the drought and changes to the water rights allocation would have effects, but the question of the magnitude and manner of those effects was unknown. However, based upon the workings of exchanges and the effects on the dilutional flows it was hypothesized that the minimum water quality constituent concentrations would increase.

The drought in Colorado began in the fall of 1999, beginning of water year 2000 (Pielke et al., 2004), and has persisted in some form throughout Colorado since that time. Directly, drought affects the owners of junior water rights first, and then older water rights fail to become filled as the waters in a river system become limited. Water rights into Barr Lake, at the Burlington Headgate on the South Platte River, Commerce City, Colorado date to the 1885 primary water rights for 13,568,000 $m^3$, 28,370,000 $m^3$ as a second priority with 37,004,000 $m^3$ refill rights (M. Montoya, FRICO, Pers. Comm., 2001). Thus multiple rights, each with changing priority, complicate influent timing. Except for extreme droughts, the first and second priority rights are filled.

Barr Lake is located approximately 30 km northeast of Denver, Colorado, USA. The lake is filled through a single canal, the O'Brian Canal, which originates as the Burlington Canal at the South Platte River in Commerce City, Colorado. The South Platte River at the point of diversion to Barr Lake is considered to be effluent dominated (Dennehy, et al. 1993). Additional wastewater is input to the Barr Lake system by directly pumping into the Burlington Canal at the Metro Wastewater Reclamation District (MWRD) treatment plant. Wastewater from the MWRD is discharged into the Burlington Canal upstream of the reverse-siphon under Sand Creek.

Barr Lake is operated as an irrigation water - storage reservoir and is thus subject to large water - level fluctuations each water year. The volume of Barr Lake at maximum capacity is approximately 40,705,500 $m^3$ with a maximum depth of approximately 10 m. The Barr Lake irrigation system has been the subject of several water - right exchanges. The result of these exchanges is an increase in the quantity of secondary wastewater treatment plant effluent directly entering Barr Lake system. These exchanges exacerbate the drought effects to the influent water quality.

## 2. Methods

For the Barr Lake System, samples were collected on approximately an every-other week basis with samples delivered unpreserved, on ice at approximately 4 degrees Celsius to the MWRD laboratory for chemical analysis. Physical measurements of specific conductivity, pH, dissolved oxygen occurred in the field using a multiprobe, which is calibrated prior to departure and the calibration is confirmed to be within 10% at the end of the day.

Only data from the Barr Lake inlet were used for this analysis, but data for the lake, in multiple locations, outlet structures and multiple locations along the filling canal are also associated with the Barr Lake System. The inlet location was only sampled when water was diverted into Barr Lake and being an off-channel reservoir, the flows were inconsistent and based upon water rights allocation. Barr Lake inlet is classified as a canal; there are no water quality standards or criteria for this location in the State of Colorado. However, there are standards at South Platte River at the Burlington Headgate, and for Barr Lake itself. Water quality data from the inlet were initially examined by plotting the data with time.

Discharge numbers are from the US Geological Survey (USGS) for the South Platte River at Denver, Colorado (06714000) (USGS, 2004). Data are from October 1997 through September 2002. Discharge numbers are from the Farmers Reservoir and Irrigation Company (FRICO) for the same period of record. Direct discharge from the MWRD is from the MWRD records and is corrected for the volume that flows into Barr Lake, since a percentage is diverted from the Burlington Canal/O'Brian Canal to other locations.

## 3. Results and Discussion

Based upon the decision to classify water years 1997 – 1999 as "normal" years and 2000 – 2002 as drought years there were difference in the flow volume into Barr Lake and in the South Platte River at the Denver Gage (Figure 1). However, the timing of spring rains in the basin in 1999, and subsequent high flows in the South Platte River determined some of the feasibility of filling water rights based upon reservoir operations.

One of the most significant differences between the normal and drought years is the timing of the waters into the reservoir. The monthly mean discharge at the inlet for the normal and drought years is listed in Table 1. The table also lists the mean annual percent of the influent on a monthly basis. Therefore the months of December, January and February illustrate the effect of the drought on the water timing. The sum of the percent influent for the normal years in December, January and February is approximately 10% of the annual influent, whereas in the drought years this sum is approximately 34%. The change in timing to a dependence on winter filling is shown in Table 1.

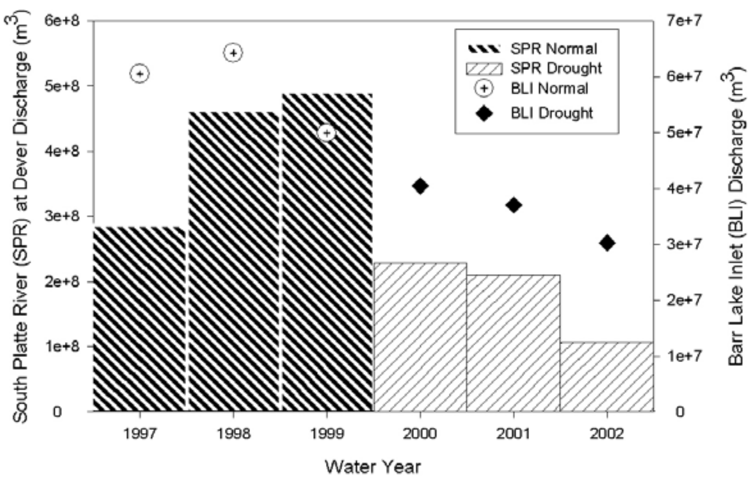


**Figure 1.** Discharges at the South Platte River and the Barr Lake inlet between normal and drought water years (Note: Differences in the Y-axis magnitude).

May, June and July demonstrate the modified flow volumes into the reservoir from an alternate point on the hydrograph. The late spring/summer flows are typically the most dilute flows in a snow dominated hydrograph, but the drought influenced timing essentially removed those flows from supplying Barr Lake with this water with a lower water quality constituent concentrations. In the normal years these three months supply 44% of the annual influent, but only 24% in the drought years.

In the drought years, the winter months supplied over 3 times the normal annual discharge into Barr Lake from these concentrated flows in the South Platte River. While in the late spring/summer months of the drought, Barr Lake received about half of its normal year allocation from diluted flows. There was a shift in the dominant filling period for Barr Lake directly related to the drought.

During the same period the direct influent from MWRD also increases. The rising proportion of direct effluent against the annual influent is shown in Figure 2. The proportion of the water rights fulfilled on an annual basis from direct wastewater effluent is linked to the date of the water rights and historical interrelations between the FRICO and MWRD.

The specific conductivity of the influent waters to Barr Lake is shown in Figure 3. During normal years there is a sinusoid to the conductivity values over time, so that the higher conductivities are in the winter months, and the lower conductivities are in the spring and summer. In the drought years, however, the sinusoid feature becomes less apparent with more samples with higher conductivities. There is a decreased variability in the conductivities and an increase in the lower conductivities as the drought continues from 2000 to 2002. Figure 3 illustrates the effect of the drought on water quality using conductivity as a primary indicator. The backdrop of the influent discharge in the figure depicts the decreasing annual inflow along with the rise in the minimum conductivities.

**Table 1.** Mean Normal and mean Drought year discharges to Barr Lake, and the percent of the mean annual discharge.

| | Mean Normal Discharge ($m^3$) | Mean Drought Discharge ($m^3$) | Normal Annual Percent | Drought Annual Percent |
|---|---|---|---|---|
| October | 4,916,000 | 874,000 | 9% | 2% |
| November | 7,248,000 | 3,638,000 | 12% | 11% |
| December | 2,375,000 | 5,416,000 | 4% | 15% |
| January | 648,000 | 3,442,000 | 1% | 11% |
| February | 3,195,000 | 2,900,000 | 5% | 8% |
| March | 3,204,000 | 3,241,000 | 6% | 9% |
| April | 3,862,000 | 3,906,000 | 7% | 10% |
| May | 8,629,000 | 5,246,000 | 14% | 14% |
| June | 8,619,000 | 3,200,000 | 15% | 9% |
| July | 8,035,000 | 341,000 | 15% | 1% |
| August | 5,756,000 | 1,066,000 | 9% | 3% |
| September | 1,715,000 | 2,635,000 | 3% | 7% |

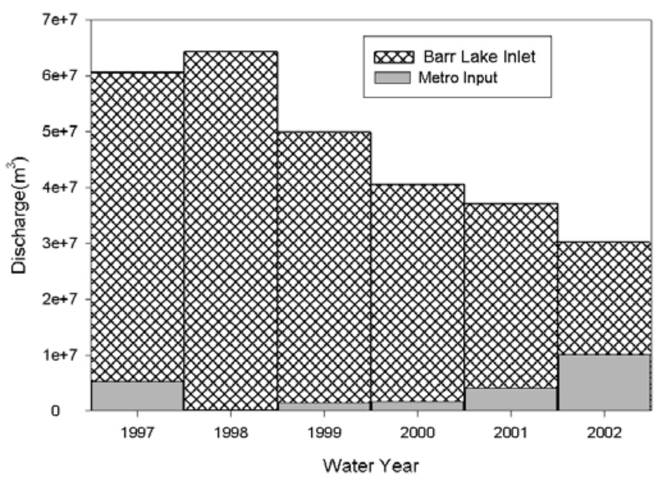


**Figure 2.** Barr Lake influent volume and volume of influent directly from the Metro Wastewater Reclamation District.

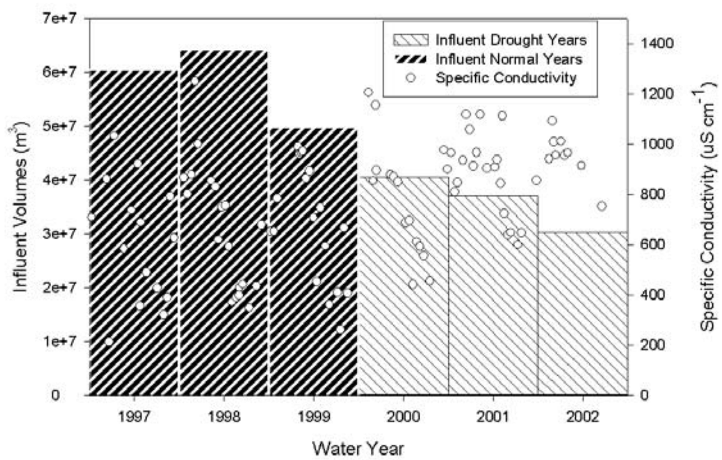


**Figure 3.** Barr Lake inlet specific conductivity (uS cm$^{-1}$).

The calcium concentrations in the influent waters also display similar changes. Calcium concentrations have increasingly greater minimum concentrations during the drought years than in the normal years (Figure 4). Sodium, sulfate and chloride concentrations also follow a similar pattern for increasing minimum concentrations as the drought proceeds (Figures 5 - 7).

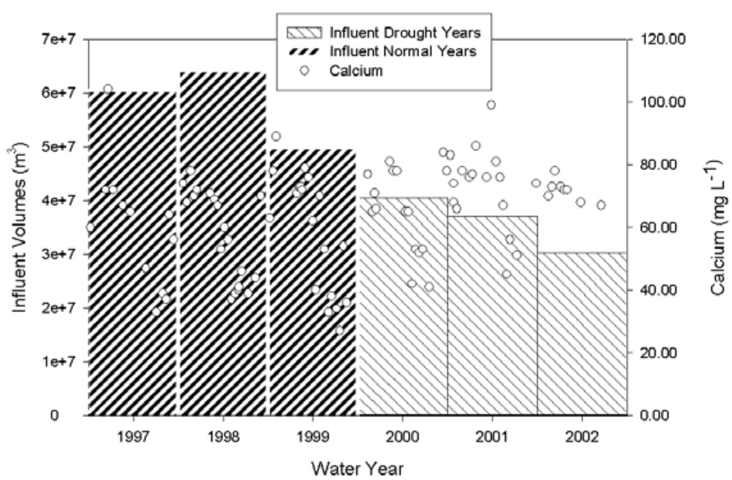


**Figure 4. Barr Lake inlet calcium concentrations (mg L$^{-1}$).**

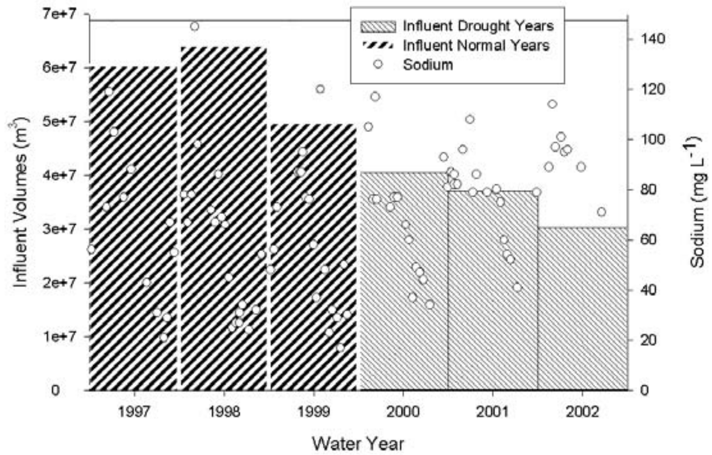


**Figure 5.** Barr Lake inlet sodium concentrations (mg $L^{-1}$).

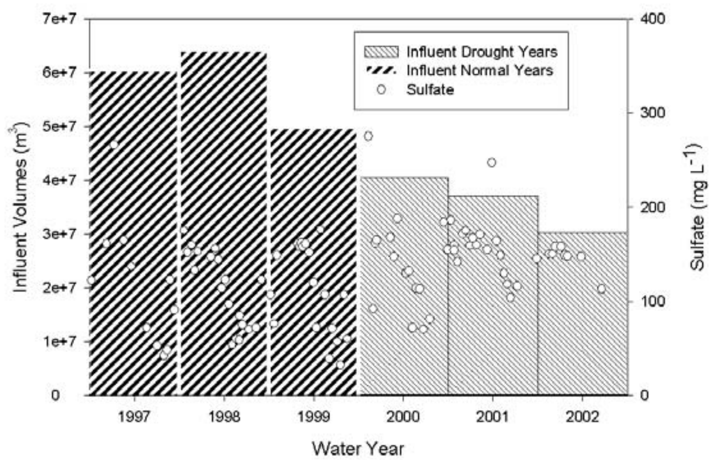


**Figure 6.** Barr Lake inlet sulfate concentrations (mg $L^{-1}$).

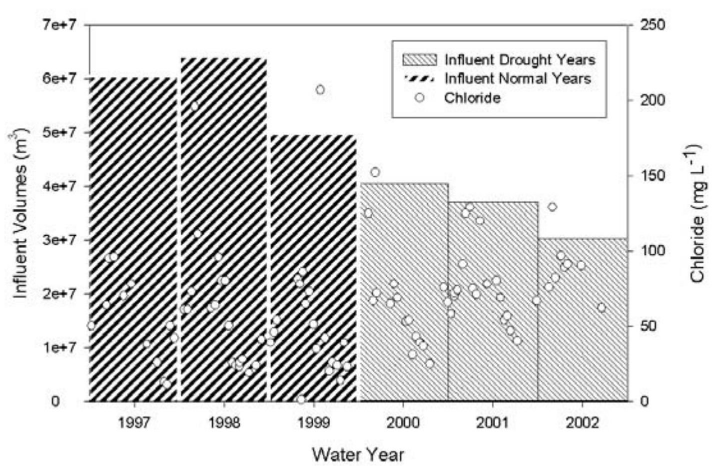


**Figure 7.** Barr Lake inlet chloride concentrations (mg $L^{-1}$).

Nitrogen concentrations still have some low concentrations in the influent to Barr Lake during the drought (Figure 8). However during the drought there are more samples with nitrogen concentrations above 6 mg $L^{-1}$. The nitrogen is measured as nitrate plus nitrite as N.

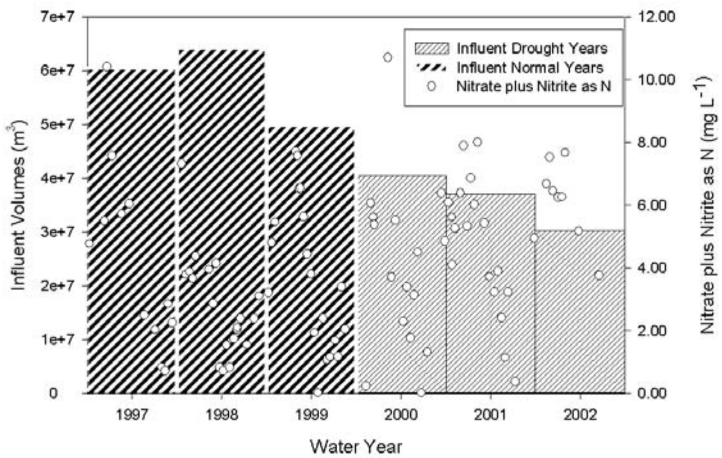


**Figure 8.** Barr Lake inlet nitrate plus nitrite as N concentrations (mg $L^{-1}$).

Phosphorus concentrations into Barr Lake are measured as both total phosphorus and as orthophosphate as P. There is a high correlation between the total phosphorus and the orthophosphate as P so that often the orthophosphate as P species is nearly 100% of the total phosphorus. Orthophosphate measurements are often utilized as the bioavailable fraction of phosphorus. Phosphorus concentrations appear to have increased in both the minimum and maximum concentrations during the drought as compared to the normal years. These phosphorus concentrations often exceed one (1) mg $L^{-1}$ during 2002.

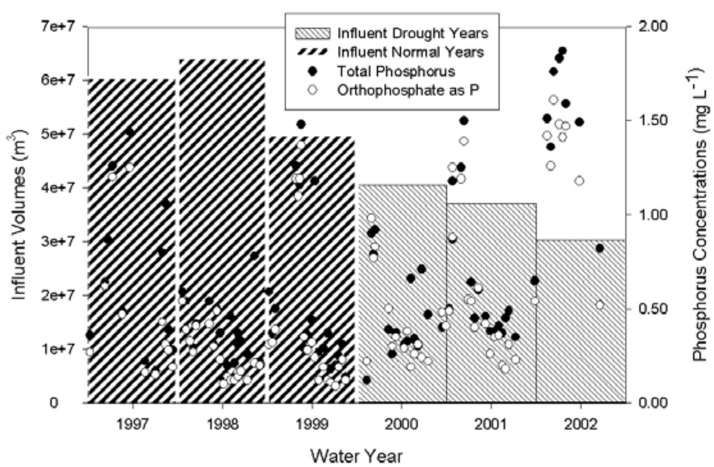


**Figure 9.** Barr Lake inlet total phosphorus and orthophosphate as P concentrations (mg $L^{-1}$).

There is an upward shift in the minimum concentrations in the influent waters to Barr Lake. This shift decreases variability and subsequently increases the mean annual concentration. Since winter flows volumes are controlled by effluent, and not runoff, in normal years and drought years the effect of the drought on the winter flows and water quality is less apparent. However, the decreased discharge in the spring and summer months directly effects the water quality by a lessening of the dilutional flows.

## 4. Conclusions

There was a shift in the regular filling period for Barr Lake directly related to the drought. In the winter months, the percentage of the drought year influent was 3 times the normal year influent. While in the late spring/summer months, during drought, Barr Lake received nearly half of the normal influent from those diluted flows. Besides decreasing the annual flow volume, the drought changed the timing and percentage of influent waters to periods of limited dilution. These winter flows are typically more chemically concentrated than spring flows, thus the greater percentage of the annual inflow has water quality effected by the drought.

The water quality effects from the drought are not from increasing of the maximum chemical concentrations, but increasing the minimum concentrations. The increases in the minimum concentrations lead to an increase in the mean concentrations. Combined with the mean chemical concentration increase, the percentage of concentrated winter flows also serves to increase the overall influent constituent concentrations, which directly effects loading calculations.

Since water quantity and water quality are regulated without being interconnected, there may be water quality objectives that cannot be met during droughts under the current system. Any future planning for droughts must incorporate water quality issues in addition to supply issues. Drought planning must include the idea that in the semi-arid west there is always a downstream user.

## 4. References

Dennehy, K.F., D.W. Litke, C.M. Tate, and J.S. Heiny, 1993. South Platte River Basin -- Colorado, Nebraska, and Wyoming. Water Resources Bulletin, vol. 29, no. 4, p. 647-684.

Pielke, R.A. Sr., N. Doesken, O. Bliss, T. Green, C. Chaffin, J.D. Salas, C. Woodhouse, J.L. Lukas, and K. Wolter: Drought 2002 in Colorado - An unprecedented drought or a routine drought?. Submitted to PAGEOPH, 6 February 2004. http://ccc.atmos.colostate.edu/. Downloaded 25 January 2005.

US Code. Federal Water Pollution Control Act (33 U.S.C. 1251 et seq.). Also known as: The Clean Water Act. http://www.epa.gov/region5/water/pdf/ecwa.pdf. Downloaded 30 August 2004.

US Geological Survey. 2004. http://nwis.waterdata.usgs.gov/nwis/discharge/?site_no=06714000. Downloaded 21 January 2004.