INCORPORATING THE COLD-WATER POOL IN LAKE LANIER CONSERVATION STORAGE MANAGEMENT

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Abstract Lake Lanier typically declines during the summer and fall to meet downstream flow requirements. While low lake levels during the summer and fall of 2007 caused concerns about depleting the conservation pool, another concern is the depletion of the cold-water (hypolimnetic) pool that lies below the surface warm-water (epilimnetic) pool. Typically, the lake is stratified during the summer. Discharges at Buford Dam are mainly from the deeper, cold-water pool, which is normally replenished during the winter and spring. The Buford Fish Hatchery - and the designated trout stream downstream of Buford Dam - depends on these cold-water releases. Increased lake discharges may exhaust this pool of cold water before winter inflows replenish it. This study uses historic data to predict the potential decline of the cold-water pool as a function of reservoir releases. The decline may be used to forecast downstream water quality impacts resulting from alternative Lake Lanier operations.

INTRODUCTION

Lake Lanier is a key water resource for the Atlanta Metropolitan Area, as well as for the downstream, tri-state (FL, AL and GA) watershed. The lake consists of 1) a *conservation pool* (defined as the volume of water between stages of 1035-1070 ft during the winter, and 1035-1071 ft during the summer, corresponding to approximately 1,049,400 and 1,087,600 AF, respectively), 2) a lower, *inactive pool* (extending from 917-1035 ft), and 3) a higher, *flood-control pool* (extending from 1070/1071 ft to the spillway elevation of 1085 ft).

These stage-defined pools do not correspond to water with unique water qualities, however. During the winter and early spring (approximately January through April), stored water is of nearly homogeneous composition. Because the lake is stratified during late-spring, summer, and fall, a warmer, oxygen-rich pool near the surface (called the *epilimnion*) overlies a cooler, hypoxic or anoxic pool at depth (called the *hypolimnion*). The warm-water pool increases during the summer and fall, but eventually cools and mixes with the underlying hypolimentic zone during late fall and early winter (shown in Figure 1).

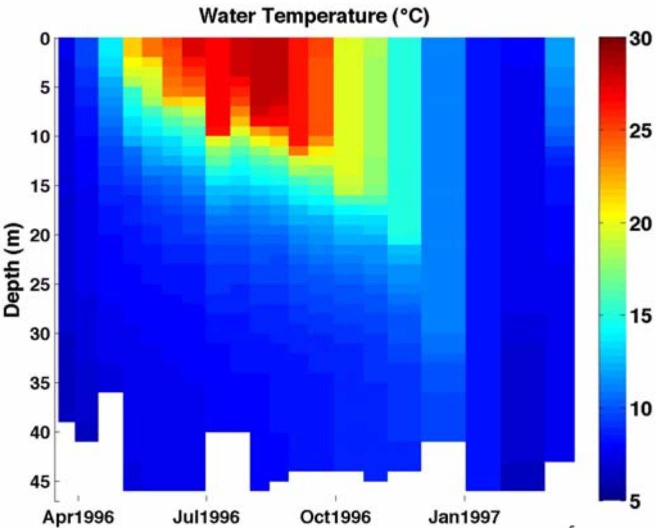

Figure 1. Water temperature variation with depth and time near Buford Dam

Figure 2 (top) presents a record of water temperatures in the Chattahoochee River downstream of Buford dam during the 3.5-year period from February 2004 through September 2007. The lowest temperatures are observed between February and March, while highest temperatures are found between November and December

Average water temperatures in the Chattahoochee River downstream of Lake Lanier range from approximately 7 to 13°C, and result from releases mainly from the deeper portion of the reservoir. Surface-water temperatures during the summer are much warmer, averaging approximately 30°C, but are mainly held in the reservoir due to the design of the structure.

Figure 2 (bottom) shows how daily stream temperatures change as the result of incident solar radiation during the mid-day period, and a peak attributable to releases from Buford Dam. It should be noted that baseflows are continuously supported using a single 6-MW turbine, while a pair of 40-MW turbines are used to generate peak electrical demand. The increased temperatures during peaking operations is likely due to the capture of overlying, warmer water within the reservoir pool.

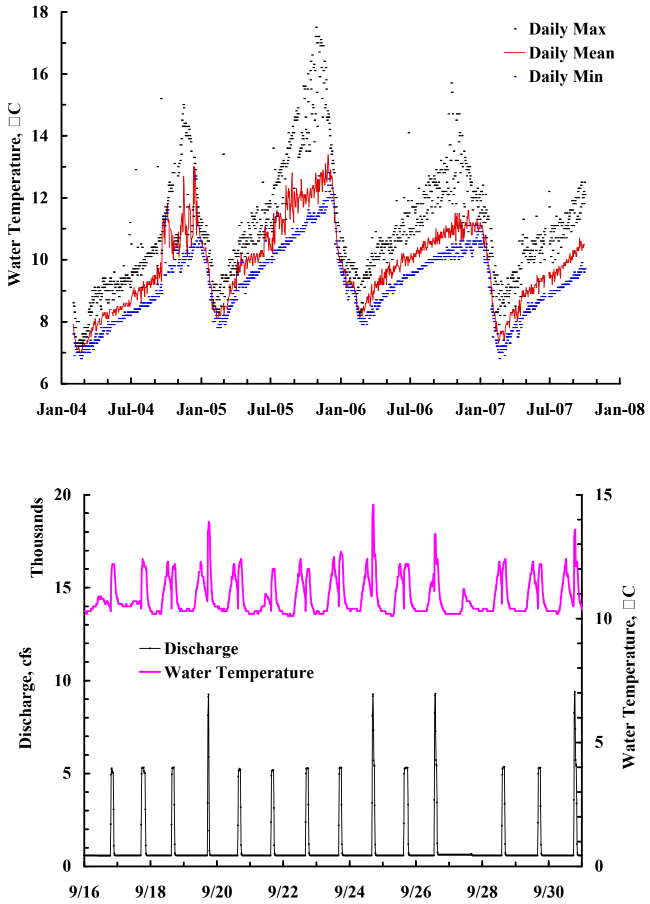

Figure 2. Annual (top) and daily (bottom) variation in water temperatures at USGS gaging station 0233430, Chattahoochee River at Buford Dam

These cool temperatures help support a cold-water fishery below Buford Dam, including the southernmost population of trout in the United States. These flows also provide sufficient cold water for the Buford Fish Hatchery, located approximately two miles downstream of Buford Dam (Figure 3).

PROBLEM STATEMENT

Of significant concern to aquatic resource managers is the alteration of stream temperatures that might jeopardize the unique fisheries habitat downstream of Buford Dam. There are several scenarios that could lead to elevated temperatures that would be lethal to fish. The most devastating scenario would be the depletion of the cold-water pool within Lake Lanier during droughts. Increased releases from the hypolimnion could diminish this pool, causing excessive temperatures downstream. Because this scenario would be caused by operations of the reservoir, it is imperative that studies be performed to help the operating agency avoid these unwanted consequences.

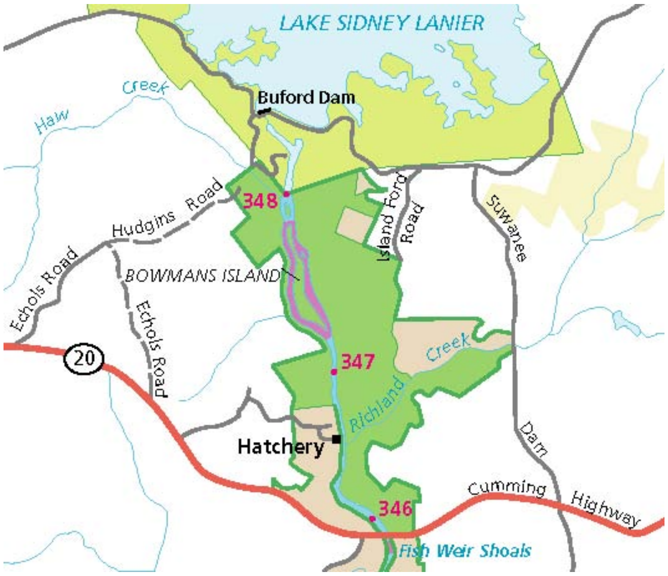

Figure 3. Location of Buford Fish Hatchery below Buford Dam.

A second possibility is a large storm that causes the reservoir to spill (i.e., the stage exceeds 1085 ft) during the summer, causing epilimnetic discharges and a large temperature anomaly downstream. A final scenario would be runoff from impervious surfaces associated with regional development near the Chattahoochee River below Buford Dam that causes thermal pollution during the summer, and the possibility of a loss of fish habitat.

This paper addresses the first scenario, i.e., a cold-water pool diminished to the point that it can no longer support a cold-water fishery below Buford Dam. We use historic data in conjunction with alternative release strategies to evaluate the possibility of an undesired depletion of the cold-water pool.

METHODS

Typically, water levels and storage volumes decline during summer and fall months. The cold pool (here narrowly defined as the pool of water with temperature at or below 15°C) also declines in the corresponding period. It has been observed that the cold pool declines at a faster, and at times much faster, rate than the total storage. A reasonable assumption is that most of the water released through turbines comes from the cold pool. It is also reasonable to further assume that the decline in the cold pool is a function of the total volume of water releases with an additional loss of cold pool by heat exchange.

A mass-balance approach accounting for changes in the cold-water storage over time is:

$$\Delta V_w = I - O \qquad (1)$$

where $\mathbf{V_w}$ is the volume of water within the storage pool, and **I** and **O** are the inflows and outflows to the pool, respectively. Lake inflow is computed by the Army Corps of Engineers using recorded releases and changes in lake surface elevations. Computed inflows include the effects of net water removals by communities adjacent to the lake as well as lake evaporation losses.

The change in the cold-water volume results from releases and thermal exchanges between warm pool and cold pool. We assume that inflows of cold water during the stratification period can be neglected because the primary mechanisms for heat loss are atmospheric exchanges during the winter, along with winter inflows of cold water. The equation describing this behavior is:

$$\Delta V_c = L - O \qquad (2)$$

Where $\mathbf{V_c}$ is the volume of cold water within the reservoir, and **L** is a volume of cold water that has been lost due to thermal exchanges, which can be found by substituting: Substituting equation (1) into equation (2), we obtain:

$$L = I + \Delta V_c - \Delta V_w \qquad (3)$$

In this system of equations, the inflows and outflows are found from historical records, the volume of water in conservation storage is found using the reservoir stage, and the volume of cold water is found using historical records of lake temperatures (and depth relationship).

If we revise the assumption so that only a fraction of the release is from the cold pool, then equations (2) and (3) can be revised to:

$$\Delta V_c = L - \alpha\, O \qquad (4)$$

$$L = \alpha\, I + \Delta V_c - \alpha\, \Delta V_w \qquad (5)$$

Where α is the fraction of release that is from the cold pool storage and lies between 0 and 1.

RESULTS

Table 1 summarizes water budget calculations using equation (3) presented in the previous section (for the period of early summer to late fall). Note that water balance calculations were not possible in several years (1987, 1993, 1994) because the temperature profiles collected in those years span less than two months and did not provide sufficient information for estimating the amount of storage change from early summer to late fall.

Table 1 shows that the amount of change in cold-pool storage because of heat exchange ranges from a loss of more than 200,000 AF to a gain of almost 200,000 AF.

Table 1. Summary of annual water budget calculations for Lake Lanier (in AF).

Year	ΔV_w	ΔV_c	L
1980	-281,800	-526,704	66,267
1981	-319,012	-402,921	-5,396
1982	-72,532	-350,720	-23,767
1983	-189,100	-267,923	25,273
1984	-241,669	-348,913	106,926
1985	-158,871	-413,730	-78,203
1986	-191,820	-294,006	-64,325
1987			
1988	-56,323	-148,771	2,006
1989	-43,160	-474,024	102,355
1990	-225,470	-283,982	191,628
1991	-215,856	-583,125	145,075
1992	5,348	-482,745	-17,910
1993			
1994			
1995	1,110	-343,525	-10,830
1996	-205,436	-343,468	66,913
1997	-125,328	-238,011	166,539
1998	-183,535	-326,338	50,590
1999	-151,153	-445,012	-99,930
2000	-299,005	-451,596	-42,554
2001	-31,445	-301,578	-99,805
2002	-172,520	-314,299	-40,979
2003	-120,200	-682,275	46,999
2004	-17,954	-689,473	-203,132
2005	-74,284	-556,727	149,204
2006	-154,180	-229,788	76,227
2007	-265,597	-339,892	-464
2008	-115,556	-256,592	2,204

Typically, there is a loss by heat exchange in the drier years, as shown in 1985, 1986, 1999, 2000, 2001, 2002, and 2004. However, we did observe steady cold-pool storage in the drought years of 1981, 1988, and 2007. A large gain in cold-pool storage tends to be associated with years of abundance, with the exception of 2006, which was the last wet year before the current drought.

Figure 4 shows the amount of cold-pool change for 25 years of observations. It is worth noting that the fraction of release from the cold pool affects the cold storage by heat exchange. For example, if we assume that only 90% of the release was from the cold storage and the rest was from the warmer layer, then the loss of cold storage by heat exchange was about 250,000 AF in 2004.

Projections of cold pool depletion can be made using this formulation. For example, Lake Lanier experienced a decline in total storage of 340,000 AF from June 1 to November 30, 2007 (from a surface elevation of 1067.2 to 1051.8 ft). The total loss of cold pool storage could be approximately 600,000 AF, assuming a worst-case loss by heat exchange of 200,000 AF.

In the early summer of 2007, the top of the cold pool lay at approximately 1030 ft. If 600,000 AF of total cold-pool loss were experienced, the top of cold pool at the end of fall could be at approximately 984 ft. This would be a mere twenty feet above the penstock elevation.

Over the last three decades, the cold pool tended to lie between 30 and 80 ft below the lake surface, with an average depth of 41 ft. If Lanier had a lower surface elevation (e.g. 1050 ft) in early summer of 2007, then the top of the cold pool would be at 955 ft toward the end of fall. This assumes that the reservoir would lose the same storage volume, and the cold pool starts the summer at 41 ft below the surface. If this had been the case, then the cold pool would be nearly exhausted, and releases from the warmer pool would constitute a large fraction of the total release, potentially causing devastating harm to the fish hatchery and the trout fishery in the Chattahoochee River downstream of Lake Lanier.

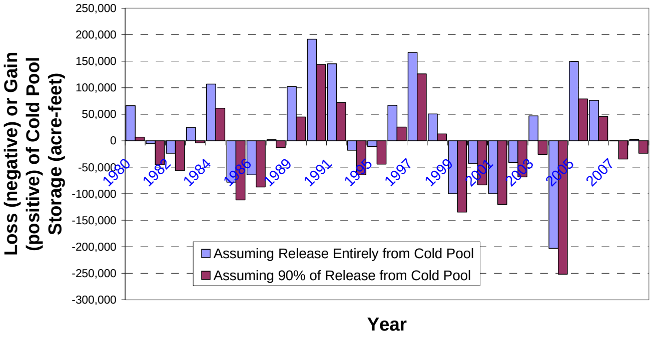

Figure 4. Change in cold-water storage due to heat exchange.

CONCLUSIONS

Increased utilization of reservoir storage during prolonged droughts may have unintended environmental and economic consequences. While reservoir management strategies have been developed for maximizing social and environmental benefits, these policies are only optimal if all appropriate impacts have been identified. This paper presents data and analyses that indicate that important downstream aquatic habitats could be adversely affected if appropriate reservoir management actions are not considered.

Specifically, we show that the depletion of the cold-water pool within the hypolimnion of Lake Lanier has the potential for exceeding maximum tolerable water temperatures for fish species below Buford Dam. Because the volume of cold water within the reservoir is finite, low lake levels coupled with increased discharges during droughts may diminish the volume of cold water within the reservoir to the point where elevated thermal discharges from the reservoir could reach lethal levels, causing significant diminution in fish populations, as well as the number of river miles with suitable habitat for cold-water fish.

A water-budget analysis was used over a 25-year period from 1980 to 2008 (with three missing years due to insufficient sampling) to estimate the loss of the cold-water pool. The calculated loss using the water budget was compared to observed changes in cold-water volume using lake water temperature measurements, and shown to substantially differ in some years. This discrepancy is attributed to heat losses (or gains) due to thermal exchanges.

In worst-case scenarios, the combination of low lake levels and elevated discharges could result in elevated temperatures of lake releases in the fall, (therefore, threatening the unique fisheries habitat downstream of Buford Dam.)