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THE EFFECT OF THE USE OF PLASTIC SHIPPING CONTAINERS ON LABORATORY MEASUREMENTS OF DISSOLVED OXYGEN

Tennessee Valley Authority
Water Resources Division

Chattanooga, Tennessee

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ON LABORATORY MEASUREMENTS OF DISSOLVED OXYGEN

Prepared by

Joseph P. Fehring
Department of Water Quality

Chattanooga, Tennessee

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EXECUTIVE SUMMARY

The use of plastic shipping containers from October 1976 to September 1984 resulted in DO measurements in the tailraces of the Tennessee River Dams being significantly lower than actual DO. The magnitude of the error in each measurement varied with the DO concentration, time between collection and analyses, and condition of the shipping container. Due to the variability in the error, DO data in the STORET files for this period cannot be individually adjusted. The data may be of some future use as a set. Therefore, these data should be locked in STORET and access allowed only to those who understand its limitations.

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INTRODUCTION

Dissolved oxygen (DO) concentrations are often used to define the water quality of a stream or reservoir. In the Tennessee Valley, there is a commonly held belief that water quality in general, and DO in particular, is declining in TVA reservoirs. In 1980, TVA conducted a study of DO trends in the tailraces of Tennessee River Dams and found a downward trend in most reservoirs, with the greatest decrease in the downstream reservoirs. This report examines a change in sampling procedures which may have contributed to the perception of declining DO.

Reservoirs typically operate in a predictable manner. The upstream portion of the reservoir behaves like a river (the flow is vertically mixed), while the downstream portion is lakelike during the summer (it thermally stratifies). The result of thermal stratification is the physical separation of waters in the lower depths (hypolimnion) from sources of reaeration. Oxygen demand in the hypolimnion caused by organic matter in the water and sediment will lower the DO concentrations faster than oxygen can enter through the barrier caused by the temperature difference (thermocline). The DO concentrations of the water in the hypolimnion will depend on several factors. These include the DO concentrations of water entering the hypolimnion, oxygen demand, retention time of the water in the hypolimnion, and the effectiveness of the thermocline in preventing reaeration.

The intakes to the hydropower generation units of most dams are located in the hypolimnion, thus the generation of electricity often results in low DO in the water immediately downstream from dams

(tailwater). Because tailwaters are often used as spawning areas and the young fish are more susceptible to low DO than adults, low DO in tailwaters has a serious impact on fish. Additionally, if another reservoir is downstream, then the water entering the hypolimnion of the downstream reservoir may be already low in DO.

The Tennessee River is impounded by a series of nine dams along most of its length, beginning with Kentucky Dam at river mile 22.4, and ending with Fort Loudoun Dam at mile 602.3. Except for the river downstream from Kentucky Dam, all of the Tennessee River is impounded when reservoirs are at the normal summer elevations. This report covers the nine Tennessee River Dams.

BACKGROUND

TVA began measuring the temperature and DO of water releases from its dams in 1949. These data have been used extensively. Monitoring has continued for almost 40 years because the data are perceived as being useful as indicators of regional water quality trends and because the monitoring program is relatively inexpensive.

Since the beginning of the program, Power personnel at TVA hydro plants and ALCOA personnel at their plants had made the temperature measurement and collected and treated a sample for the DO measurement. The sample was then shipped to TVA's laboratory in Chattanooga where the titration was performed to complete the analysis.

Until the autumn of 1976, the DO samples were shipped in glass bottles. Because of the possibility of glass breakage, 250-ml plastic containers from the autumn of 1976 until the summer of 1984. In the

method used in the laboratory to measure DO, iodine released from a reagent added to an acidified DO sample is measured. The iodine is released on a one-to-one basis to the DO in the sample. By 1983, several TVA organizations had become aware of a discrepancy in DO measurements caused by the use of plastic containers. The plastic containers apparently absorb some of the iodine resulting in low DO measurements.

This reduction in measured DO was verified by Field Operations in July 1983 and documented in a memorandum from David G. Page to Jack M. Garrison on August 24, 1983 (4). In the memorandum, David Page noted that some plastic containers possessed a dark brown color, indicating that free iodine, which has a brownish color, had been adsorbed on the surface of the containers. The memorandum describes the following test of the error in DO measurements caused by using plastic containers.

A set of 11 samples was collected at Boone Dam on July 19, 1983, along with a 9-sample set at Fort Patrick Henry Dam and an aerated set of 9 samples. Three samples of each set of samples were analyzed at the collection site, three more of each set were sent to the laboratory in 250-ml plastic containers for analyses, and the remaining three or five samples of each set were taken back to the Field Operations office in Norris for analyses. The results of these analyses are summarized in table 1.

The differences in the mean DO for these samples varied from 0.8 mg/l for the Fort Patrick Henry samples to 1.3 mg/l for the aerated samples. The smallest difference occurred in the sample with the lowest DO, and the greatest difference occurred in the set with the highest DO.

Table 1. Boone and Fort Patrick Henry Penstock Samples

Sample Location	Mean DO (mg/l)		
	Field	Norris	Laboratory
Boone	6.2	5.8	5.3
Fort Patrick Henry	5.5	5.5	4.7
Aerated	7.5	7.2	6.2

SCOPE OF PRESENT STUDY

This report has the following goals:

1. Determine what, if any, impact on measured DO resulted in the change from glass to plastic sample bottles.
2. Recommend corrective action for documented errors.
3. Examine effects of streamflow on measured DO to determine whether observed trends may be the result of variations of streamflow.

PREVIOUS ANALYSES OF DO TRENDS

In November 1980, TVA released a report entitled "Dissolved Oxygen Trend Analysis In Releases From Mainstem Dams On The Tennessee River" (1). The report concluded that DO concentrations decreased in recent years (1975-79) when compared to the long-term (1960-79) average. The greatest rates of decrease were in Kentucky and Pickwick Reservoirs.

As mentioned in the Background section of this report, the change from glass to plastic containers in the fall of 1976 may have resulted in biased data that is not directly comparable to previous data. The 1980 report found that DO during the 1975-79 period was lower than the 20-year

average, but had not considered the impact of a change in sampling method. If DO measurements were artificially low during three of the five years in this period due to the use of plastic containers, DO would be lower than the 20-year average.

ASSUMPTIONS AND LIMITATIONS

This analysis only uses DO concentrations in the tailraces of the Tennessee River Dams during the summer months when low DO conditions detrimental to aquatic life are most likely to occur. The same period of record was used for each dam.

Hydropower generation at Nickajack began in February 1968. Thus, the first year of data used for each of the dams in this analysis was 1968. Only DO data for the four months of June through September were used. Reservoirs stratify at different times from year to year, and all reservoirs do not stratify at the same time. Thus, it was necessary to use a somewhat arbitrary time period to represent the summer, or stratified period. The four months of June through September were, in the judgment of the author, the best approximation of the time each year when all nine reservoirs were most likely to be stratified. The last year of data used was 1983 because the summer of 1984 was a transition period in methods of DO measurement.

Dissolved oxygen concentrations in dam releases are generally lowest immediately after power generation begins and increase if generation continues for several hours as surface water begins to be

drawn into the intake. Dissolved oxygen samples are not always taken at the same time during the generation period and thus individual weekly samples may not be comparable to each other. However, it is assumed that the variations caused by different sampling times will be cancelled out by averaging the approximately 16 weekly samples to obtain yearly summer DO concentrations.

DATA ANALYSES AND PRESENTATION

Weekly DO measurements in the tailraces of the nine dams used in this study comprise the data base. Dissolved oxygen measurements during the four months June through September of each year from 1968 through 1983 were averaged to obtain a mean DO for each dam and year. Statistical computations were performed by Data Management.

Regression coefficients were calculated for the mean summer DO in the tailrace of each of the nine dams using the method of least squares to determine the average yearly change in measured DO during the sixteen years covered in this study (1968-83). Except for Chickamauga and Watts Bar, DO shows a downward (negative) trend at all dams (table 2), with the greatest decline at the four most downstream dams. This agrees with the conclusions of the 1980 report on DO trends. The significance shown in the last column is the probability that the direction of the calculated trend is correct. In other words, there is a 97.2-percent probability that the measured DO in the Kentucky tailrace decreased from 1968 to 1983. A probability of 95 percent or higher is considered statistically

Table 2. Trends in Measured Summer Dissolved Oxygen

Dam	Trend (mg/l/yr)	Probability
Kentucky	-0.078	0.972
Pickwick	-0.112	0.992
Wilson	-0.057	0.861
Wheeler	-0.085	0.982
Guntersville	-0.016	0.416
Nickajack	-0.037	0.898
Chickamauga	0.022	0.395
Watts Bar	0.020	0.342
Fort Loudoun	-0.005	0.127

significant; thus, the downward trends in DO in the tailraces of Kentucky, Pickwick, and Wheeler are statistically significant.

Because the data for the last seven years of this 16-year period are suspect, further examination of the data is necessary. Figure 1 is a plot of the mean summer DO during the sixteen year period for Pickwick Dam. A discontinuity appears in the data between 1976 and 1977, when the change was made from glass to plastic shipping containers. This discontinuity is present for all nine dams (table 3), but is greatest for the downstream dams which show the greatest decline in measured DO.

A student's t test was run to determine whether the "glass" (1968-76) and "plastic" (1977-83) DO data comprise two independent data sets (table 4). The tests were run under the hypothesis that the mean of the two sets of data were equal. Thus a decision to reject means the 1977-83 data set is significantly different from the 1968-76 data. The two data sets are significantly different at six of the nine dams.

Chickamauga Dam, located in Chattanooga just a few miles from the laboratory, showed the smallest impact from plastic containers

FIGURE 1

Table 3. Summer DO in Tennessee River Dam tailraces^a

Year	Kentucky	Pickwick	Wilson	Wheeler	Guntersville	Nickajack	Chickamauga	Watts Bar	Fort Loudoun
First period—glass bottles, mg/l)									
1968	6.6	7.1	5.4	6.3	6.6	5.7	5.8	4.7	4.7
1969	6.6	6.9	5.8	6.3	5.9	5.4	5.3	4.1	3.6
1970	6.2	7.1	5.8	6.2	6.3	5.8	5.7	4.0	3.9
1971	6.5	7.0	6.0	6.0	6.4	5.8	5.9	4.5	4.3
1972	6.9	7.5	6.2	6.6	6.9	5.7	6.3	5.6	5.2
1973	7.1	7.5	6.5	7.1	7.2	6.3	6.6	6.0	4.8
1974	7.0	7.6	6.4	6.7	6.8	6.1	6.4	6.0	4.8
1975	6.9	7.5	6.9	6.7	6.9	6.2	6.4	5.8	4.7
1976	<u>6.8</u>	<u>7.8</u>	<u>7.0</u>	<u>6.8</u>	<u>7.0</u>	<u>6.4</u>	<u>7.2</u>	<u>5.8</u>	<u>4.5</u>
Average	6.7	7.3	6.2	6.5	6.7	5.9	6.2	5.2	4.5
Second Period—Plastic Containers, mg/l)									
1977	4.9	5.8	4.8	5.2	5.4	5.3	5.5	4.3	3.3
1978	5.3	5.7	4.9	5.1	5.8	5.5	5.6	4.5	3.6
1979	6.0	6.4	6.1	6.2	6.6	5.9	7.1	6.3	5.0
1980	5.4	6.3	5.3	5.2	5.9	5.3	4.6	4.6	4.2
1981	5.6	5.9	5.0	4.9	6.9	5.0	5.6	4.3	3.8
1982	5.8	5.7	5.0	5.3	5.9	5.2	5.7	4.7	4.3
1983	<u>6.3</u>	<u>5.8</u>	<u>5.4</u>	<u>5.9</u>	<u>6.6</u>	<u>5.4</u>	<u>7.4</u>	<u>5.3</u>	<u>4.8</u>
Average	5.6	5.9	5.2	5.4	6.2	5.4	5.9	4.8	4.1
Difference	1.1	1.4	1.0	1.1	0.5	0.5	0.3	0.4	0.4

a. All values represent the average of all DO measurements between June 1 and September 30.

Table 4. T-Test on Dissolved Oxygen Data During Two Periods

Dam	<u>Equal Variance</u>		<u>Unequal Variance</u>		Decision
	Comp.-T	Sign.-T	Comp.-T	Sign.-T	
Kentucky	5.952	1.345	5.592	1.383	reject
Pickwick	9.135	1.345	9.235	1.345	reject
Wilson	4.032	1.345	4.128	1.345	reject
Wheeler	5.523	1.345	5.308	1.363	reject
Guntersville	2.150	1.345	2.069	1.363	reject
Nickajack	3.585	1.345	3.664	1.345	reject
Chickamauga	0.642	1.345	0.600	1.383	not to reject
Watts Bar	0.781	1.345	0.796	1.345	not to reject
Fort Loudoun	1.284	1.345	0.244	1.363	not to reject

(table 3). The next smallest DO reductions were at Fort Loudoun and Watts Bar, where the initial DO was lowest. The dams with the highest DO (Kentucky and Pickwick) showed the greatest impact from plastic containers.

To determine whether the oxygen demand of the plastic containers was dependent on the original oxygen concentration and the time held until analysis, laboratory tests were run in Water Quality's Unit Operations Laboratory in summer 1987. The methods, assumptions, and results are included as appendix A and are summarized in table 5.

The values shown in table 5 are the averages of triplicate samples. Using new plastic containers (concentration study), about 10 percent of the DO was lost in all samples after four days, indicating that the differences in data sets are at least partially related to the initial DO concentration. The rate lost was relatively constant over the four days indicating the difference is also related to the time between collection and analyses. With the used plastic containers (aging study), there was again approximately a 10-percent loss, but all of the loss

Table 5. Unit Operations Laboratory Dissolved Oxygen Study
(Averages of Triplicate Analyses Shown)

Time (days)	High DO		Medium DO		Low DO	
	Glass	Plastic	Glass	Plastic	Glass	Plastic
Concentration study, mg/l						
0	7.5	7.5	6.1	6.1	4.0	4.0
1	7.7	7.2	6.0	5.8	4.0	3.8
2	7.7	7.0	6.1	5.5	4.0	3.8
4	7.6	6.6	6.1	5.4	4.0	3.6
Aging study (used, plastic containers)						
Time (days)	0	1	2	4		
Dissolved oxygen (mg/l)	7.5	6.7	6.6	6.7		

occurred on the first day. Because it is not possible to determine which individual samples were sent in new or used containers, and time between collection and analyses cannot always be determined, it is not feasible to correct individual DO measurements analyzed between October 1976 and October 1984.

IMPACT OF STREAMFLOW

During the period of study, there were two years with large floods, 1973 and 1979. Dissolved oxygen was higher at each of the nine dams during these two years than the means of the two sampling periods (table 6).

The sample correlation coefficient is a measure of the direction and strength of a linear relationship between two variables, in this

Table 6. Impact of 1973 and 1979 Floods on Dissolved Oxygen
(Mean Summer Dissolved Oxygen [mg/l])

Year	Kentucky	Pick- wick	Wilson	Wheeler	Gunters- ville	Nicka- jack	Chicka- mauga	Watts Bar	Fort Loudoun
1968-76	6.7	7.3	6.2	6.5	6.7	5.9	6.2	5.2	4.5
1973	7.1	7.5	6.5	7.1	7.2	6.3	6.6	6.0	4.8
Difference	0.4	0.2	0.7	0.6	0.5	0.4	0.4	0.4	0.3
1977-83	5.6	5.9	5.2	5.4	6.2	5.4	5.9	4.8	4.1
1979	6.0	6.4	6.1	6.2	6.6	5.9	7.1	6.3	5.0
Difference	0.4	0.5	0.9	0.8	0.4	0.5	1.2	1.5	0.9

case, DO and flow. It was assumed that flow at any Tennessee River location would be somewhat representative of flow through each dam. Thus flows at Savannah, Tennessee, were used for the correlation with DO at each dam. Flows affect DO by changing the retention time in the reservoir, so flows from June through September would affect June through September DO. Antecedent conditions also affect DO, so flows from May through August would affect June through September DO. The impact of both antecedent conditions (flow related) and retention times are represented by flows for the June through August period.

Due to Spearman (2), the rank correlation coefficient (r_s) varies from 1.0, which means a perfect correlation, to -1.0, which means a perfect inverse correlation. A negative r_s value would mean that DO decreased when flow increased. An r_s value of zero means there is no correlation; in other words, the two variables are independent. Table 7 shows significant correlation between flow and DO for all dams for the 16-year period ($r_s \geq 0.497$), all dams except Fort Loudoun in the 1968-76 period ($r_s \geq 0.683$), and at four of the dams in the 1977-83 period ($r_s \geq 0.750$). The

Table 7. Rank Correlation Coefficients (r_s) Between Average Flows (June Through August) and Summer Dissolved Oxygen (June Through September)

Reservoir	Sampling Periods		
	1968-83	1968-76	1977-83
Kentucky	0.59	0.80	0.58
Pickwick	0.50	0.76	0.04
Wilson	0.70	0.88	0.57
Wheeler	0.63	0.94	0.79
Guntersville	0.67	0.93	0.09
Nickajack	0.75	0.84	0.86
Chickamauga	0.87	0.94	0.75
Watts Bar	0.93	0.89	0.85
Fort Loudoun	0.80	0.64	0.67

relative weak correlation coefficient between flow and DO during the 1977-83 sampling period may reflect the variable impact of the plastic containers on measured DO (see appendix A).

The correlation between flow and DO provides a caution in calculating trends without studying the causes. Table 8 shows trends in DO at each dam during the two sampling periods covered in this study. Seven of the nine dams show statistically significant increasing DO during the first sampling period, and Kentucky had a significant increase in the second period. Regression coefficients calculated using the average summer flow at Savannah increased by 2129 cfs per year from 1968 to 1976 and by 302 cfs per year from 1977 to 1983. These increases in flow probably account for the upward trends in DO shown in table 8.

Table 9 shows the mean summer flows at Savannah, Tennessee. The average summer flow in the 1968-76 period was 7 percent higher than in the 1977-83 period. Because DO is correlated to flow, part of the difference in measured DO between the two periods can be attributed to

Table 8. Dissolved Oxygen Trends During Two Monitoring Periods

Dam	Trend (mg/l/yr)		Probability	
	1968-76	1977-83	1968-76	1977-83
Kentucky	0.065	0.171	0.931	0.967
Pickwick	0.102	-0.018	0.999	0.225
Wilson	0.190	0.032	0.999	0.262
Wheeler	0.088	0.043	0.964	0.329
Guntersville	0.107	0.146	0.971	0.829
Nickajack	0.105	-0.043	0.997	0.529
Chickamauga	0.183	0.157	0.999	0.554
Watts Bar	0.250	0.050	0.993	0.252
Fort Loudoun	0.080	0.168	0.767	0.831

Table 9. Average Summer (June Through August, Flows at Savannah, Tennessee (cfs)

Year	Flow	Year	Flow
1968	37,850		
1969	30,980	1977	35,250
1970	33,590	1978	37,700
1971	41,330	1979	55,420
1972	42,290	1980	35,260
1973	60,040	1981	34,630
1974	46,440	1982	36,660
1975	47,250	1983	45,690
1976	<u>46,480</u>		
Average	42,920		40,090

change in flow. But does flow account for all of the difference in measured DO, or can part of the difference be attributed to the use of plastic shipping containers? In 1983, a year that plastic containers were used, the mean summer flow was 6 percent higher than the average summer flow from 1968 to 1976, yet DO was lower in 1983 at six of the dams than the average DO from 1968 to 1975. Thus, while lower flows may

account for some of the difference in DO between the two sampling periods, it does not account for all of the difference.

FIELD VERIFICATION

From 1975 to 1980, in-situ DO measurements were made at the nine dam sites of this study; 33 were collected before October 1976, when shipping containers were changed from glass to plastic, and 94 were made later. These 127 field measurements were compared to samples analyzed in the laboratory. When the field measurements were not collected on the same day as the laboratory sample, an estimated laboratory value was obtained for the date of the field sample by prorating the previous and following laboratory samples. These values are shown in appendix B and are summarized in table 10.

Table 10. Differences Between Field and Laboratory Analyses of Dissolved Oxygen (Number of Samples)

Sampling period	Differences in DO Measurements (mg/l)						
	>1.0	0.7 to 1.0	0.3 to 0.6	-0.2 ^a to 0.2	-0.6 to -0.3	-1.0 to -0.7	<-1.0
1968-76	5 ^b	3	5	9	5	1	5
1977-83	0	2	1	15	21	20	34

a. Negative values mean field measurements were larger than laboratory measurements.

b. During the 1968-76 sampling period, five samples had a DO concentration measured in the laboratory that was more than 1.0 mg/l higher than the concentration measured in the field on the same day.

The large differences between DO measured in the field and the laboratory are probably the result of collecting samples at different times during electric power generation. However, with samples shipped in glass containers, the median difference between field and laboratory measurements was 0.1 mg/l, indicating field and laboratory measurements were giving similar results. The median difference for samples shipped in plastic containers and field measurements was -0.8 mg/l, indicating that the average loss due to shipping in plastic containers was 0.8 mg/l, about the same as the average for the nine dams shown in table 3 (0.74 mg/l).

Dissolved oxygen data from the other TVA dams should be checked to determine whether the same problem applies to them, and if so, these data should be treated the same way as the data from the Tennessee River Dams.

CONCLUSIONS AND RECOMMENDATIONS

1. The change from glass to plastic containers resulted in individual DO measurements being up to ten percent lower than actual concentrations. The magnitude of individual errors varied with initial DO concentration, the time between collection and analysis, and the condition of the sampling container.
2. The data may be of some future use as a set, but individual DO concentrations are not useful due to the variability in the errors. Therefore, the DO data collected between October 1976 and September 1984 should be locked in STORET and access allowed only to those who understand its limitations.
3. There was a strong correlation between streamflow and tailrace DO during the period of the study. Future DO trend studies on the Tennessee River must account for the effects of changes in flow in order to calculate a true trend.

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APPENDIXES

APPENDIX A

UNIT OPERATIONS LABORATORY STUDY OF IMPACT
OF PLASTIC CONTAINERS ON MEASURED
DISSOLVED OXYGEN

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UNIT OPERATIONS LABORATORY STUDY OF IMPACT OF PLASTIC CONTAINERS ON MEASURED DISSOLVED OXYGEN

PROCEDURE

Iodide Adsorption

Tennessee River water collected at Ross's Landing, Chattanooga, Tennessee was the source water for the study. The water was brought to room temperature of the laboratory (24°C), and air was bubbled into it to saturate the water with oxygen.

Three dissolved oxygen (DO) concentrations, 8.0, 6.0, and 4.0 mg/l were investigated. Theoretically, DO saturation at 24°C is approximately 8.4 mg/l. Saturation under the test conditions (as determined by the Winkler method) was 7.5 mg/l, and this was used in the study as the high study concentration (~8.0 mg/l).

The testing apparatus is illustrated in figure A-1. A DO meter calibrated against the Winkler method was used to continuously monitor the DO of the water in continuously mixed 19 liter reactor. Triplicate samples were grabbed from the reactor using 300 ml BOD bottles. These were immediately dosed with manganous sulfate (MnSO_4) and alkali-iodide-azide reagent using an automatic pipettor set at 2 ml. These samples were then capped and mixed. The next set (triplicate) was then grabbed and this was continued until the total sample quantity (21) for investigating one DO concentration was collected. This was achieved before the floc in the first set of samples had settled to approximately one-third of the volume of the BOD bottle. At this point, the samples

were remixed and allowed to settle again. Two milliliters of concentrated sulfuric acid was then added to the BOD bottles and the sample mixed. The contents of half the bottles were then placed into 250 ml plastic bottles and sealed. All the samples both plastic and glass were covered with black plastic to prevent any light reaching the bottles. One set of the triplicate samples was titrated using 0.0375N sodium thiosulfate and Thyodene indicator (Winkler method) to determine the initial (0 time) DO concentration.

The reactor was refilled with river water, brought to saturation, and then lowered using nitrogen gas to strip the oxygen to 6.0 and 4.0 mg/l, respectively. The same chemical addition and physical procedure was used as discussed previously. The DO concentration was then determined in sets of the glass and plastic BOD bottles at one, two, and four days.

Iodide Adsorption and Bottle Aging

Iodide absorption and bottle aging was investigated after the iodide absorption was completed. The plastic bottles which showed the maximum, minimum, and average degree of adsorption from the previous study were used. This difference was not only evident from the data but also visibly evident from the plastic bottles. These bottles were the four day, 8 mg/l DO concentration; the one day, 4 mg/l DO concentration; and the two day 6 mg/l DO concentration.

Again Tennessee River water was used at laboratory DO saturated conditions. Triplicate samples were collected using the same apparatus, dosage rates, and physical procedure as previously discussed. The triplicate samples were titrated after four days of storage.

The results of the study examining the DO concentrations difference between glass and plastic bottles is presented in table A-1. All of the DO concentrations in the plastic bottles were lower than their counterparts in glass bottles. The difference between the plastic and glass bottles increased with detention time and with higher initial DO concentrations. These trends are especially evident in the graphic presentation of the average data presented in figure A-2.

The data followed the expected theoretical expectations of free iodine absorption on a porous substance (plastic). The greater the initial concentration and longer the detention time the greater the absorption of iodine. The absorbed free iodine is not available to be measured by thiosulfate thus resulting in a lower DO concentration than actually present.

The aging study was performed to investigate whether plastic bottles with varying quantities of iodine absorbed and then decreased the quantity of further iodine absorption. The data presented in table A-1 and figure A-3 indicate no measurable DO concentration difference was evident between the maximum and minimum iodine absorbed bottles. This characteristic, if present, would be difficult to measure within the analytical precision of the Winkler test.

by: Jeffery J. Longaker

Table A-1. Dissolved Oxygen Concentration Versus Time Glass (BOD)
Bottles and Plastic Bottles, mg/l

	CONCENTRATION STUDY					
Time/days	Glass	Plastic	Glass	Plastic	Glass	Plastic
0	7.32	7.32	6.06	6.06	3.96	3.96
0	7.56	7.56	6.06	6.06	3.96	3.96
0	7.56	7.48	6.08	6.08	3.96	3.96
Average	7.48	7.453	6.066	6.066	3.96	3.96
1	7.62	7.22	6	5.8	4.03	3.85
1	7.68	7.1	6	5.74	4.1	3.76
1	7.68	7.14			4.02	3.79
Average	7.66	7.153	6	5.77	4.05	3.8
2	7.62	7.04	6.11	5.58	3.96	3.86
2	7.75	6.94	6.1	5.51	3.98	3.78
2	7.74	6.94	6.1	5.42	3.94	
Average	7.703	6.973	6.103	5.503	3.96	3.82
4	7.62	6.66	6.22	5.35	3.9	3.77
4	7.62	6.55	6.12	5.4	4	3.67
4	7.69	6.72	6.07	5.4	3.96	3.49
Average	7.643	6.643	6.136	5.383	3.953	3.643
Total Average						
	AGING STUDY					
Time/days	0	1	2	3	4	
	7.46	6.65	6.64		6.66	
	7.5	6.66	6.62		6.66	
	7.62		6.62			
Average	7.526	6.655	6.626		6.66	

Zero Grade Nitrogen

FIGURE A-1

DISSOLVED OXYGEN TESTING APPARATUS

FIGURE A2
AVERAGE DO VERSUS TIME

FIGURE A3
DO IN PLASTIC BOTTLES VERSUS TIME

APPENDIX B

FIELD AND LABORATORY DISSOLVED OXYGEN

Table B-1. Field and Laboratory Dissolved Oxygen

Reservoir	Year	Date	Field Measurement	Laboratory Measurement
Kentucky	1975	104		10.5
		107	10.3	
		110		7.8
		321		9.8
		329	8.8	
		336		10.2
	1976	118		8.5
		119	8.4	
		123		8.0
		305		7.6
		307	9.8	
		310		6.6
	1977	157		5.0
		165	6.3	
		170		5.0
		333		9.0
		334	10.2	
		338		9.5
	1978	106		8.8
		108	13.7	
		112		7.8
		331		8.2
		333	9.8	
		337		9.2
Pickwick	1975	105		9.8
		114	9.0	
		120		10.2
		267		6.9
		268	7.2	
		274		7.4
	1976	111		8.8
		120	8.0	
		124		8.9
		306	9.2	9.2

Table B-1. (Continued)

Reservoir	Year	Date	Field Measurement	Laboratory Measurement
Pickwick (continued)	1977	143		6.7
		144	7.9	
		151		6.7
		334		8.6
		340	10.0	
		352		9.4
	1979	99		6.5
		109	9.3	
		116		6.9
		327		7.5
		332	9.6	
		338		9.9
Wilson	1975	112	9.9	8.8
		267		7.8
		269	6.8	
		273	6.8	
	1976	305		7.4
		306	9.2	
		311		8.6
	1977	145		7.1
		147	7.2	
		151		5.4
		338		9.4
		340	10.0	
		345		9.8
	1979	99		8.2
		101	8.6	
		106	8.6	7.6
		177		8.4
		179	7.5	
		184		5.6
		227	5.7	5.7
		302		7.5
		303	8.8	
		308		6.6
		332	9.1	8.2
		337	9.3	
		338	11.8	
		344		8.9

Table B-1. (Continued)

Reservoir	Year	Date	Field Measurement	Laboratory Measurement
Wheeler	1975	112	9.3	7.6
		189		7.0
		191	5.9	
		194		7.0
		266		7.1
		269	7.2	
		273		7.5
	1976	16		11.7
		17	12.0	
		22		11.6
		94		8.6
		98	9.2	
		101		9.3
	1977	59		10.0
		61	9.8	
		63		8.8
		143		7.0
		147	6.2	
		151		5.8
		339		9.3
		341	10.0	
		345		10.2
	1978	122		8.2
		123	10.3	
		128		7.4
	1979	52	12.8	8.8
		98		8.0
		101	8.7	
		105	9.0	
		113		7.7
		177		5.6
		178	7.4	
		184		5.4
		331	9.4	8.8
		337		9.2
		340	11.2	
		344		9.6

Table B-1. (Continued)

Reservoir	Year	Date	Field Measurement	Laboratory Measurement
Guntersville	1975	264		7.0
		270	7.2	
		273		7.2
	1976	152		7.6
		153	7.8	
		158		7.8
		334		7.7
		336	10.8	
		341		9.2
	1977	136		7.1
		139	7.8	
		142		7.1
		340		9.3
		342	10.3	
		345		10.2
	1978	219		5.7
		220	6.1	
		227		5.9
	1979	121		7.5
		123	7.4	
		127		7.8
Nickajack	1975	97		10.0
		101	11.0	
		104		9.6
		139		7.1
		142	6.6	
		153		6.2
	1976	130		7.6
		135	7.7	
		139		7.2
		214		5.5
		215	5.5	
		221		5.9

Table B-1. (Continued)

Reservoir	Year	Date	Field Measurement	Laboratory Measurement
Nickajack (continued)	1977	37		11.7
		38	12.5	
		45		12.2
		145		6.0
		146	6.6	
		152		6.2
		157		6.0
		159	6.0	
		168		6.5
		235		5.2
		236	7.0	
		241		5.2
		333		9.6
		334	9.9	
		340		9.4
	1978	142		6.8
		152	7.1	
		156		6.8
		206		5.4
		210	5.5	
		212		5.2
		216		5.2
		218	5.7	
		223		5.8
		241		5.2
		242	6.3	
		254		5.2
		310		6.9
		327	7.6	
		331		7.2
	1979	105		9.0
		114	8.5	
		128		7.6
		343		9.6
		347	10.1	
		351		8.8
	1980	202		4.5
		205	5.3	
		209		4.9

Table B-1. (Continued)

Reservoir	Year	Date	Field Measurement	Laboratory Measurement
Chickamauga	1975	98		10.0
		102	10.3	
		105		9.4
		139		7.1
		140	7.5	
		146		6.5
	1976	40		11.5
		42	11.4	
		47		11.6
		133		8.0
		136	7.5	
		139		7.8
		214		6.8
		215	6.3	
		221		6.8
		340		8.9
		342	11.1	
		347		8.1
	1977	38	13.2	11.7
		74		10.6
		75	10.6	
		83		9.6
		144		7.8
		146	7.6	
		151		6.6
		235		5.8
		236	6.6	
		243		5.8
		333		9.8
		334	9.8	
		338		10.0
		347		9.9
		349	10.6	
		354		10.1

Table B-1. (Continued)

Reservoir	Year	Date	Field Measurement	Laboratory Measurement
Chickamauga	1978	54		11.3
		56	12.8	
		59	11.4	
		150		6.3
		152	7.3	
		156		6.3
		213	6.5	6.1
		217		5.6
		218	6.0	
		223		5.9
		240		5.3
		242	6.4	
		248	5.7	
		316		7.2
		327	8.5	
		332		7.4
	1979	86		9.6
		88	10.0	
		93		8.5
		114		9.2
		117	9.3	
		121		8.2
		150		6.8
		151	7.6	
		155		6.5
		215		6.3
		216	6.4	
		221		8.2
		253		7.6
		255	6.8	
		258		8.2
		324		8.2
		325	8.4	
		331		8.6
		347	10.2	8.6

Table B-1. (Continued)

Reservoir	Year	Date	Field Measurement	Laboratory Measurement
Chickamauga (continued)	1980	28		9.5
		29	10.9	
		34		9.8
		63		12.7
		64	12.4	
		71		9.9
		105		8.2
		108	10.5	
		112		7.6
		167		5.5
		169	7.0	
		173		5.8
Watts Bar	1975	139	6.6	6.9
		245		5.3
		258	6.1	
		264		10.2
	1976	166		5.4
		167	3.9	
		172		5.2
		214		7.3
		215	5.6	
		221		6.4
		300		8.4
		307	9.0	
		310		8.2
		340	11.9	8.6
	1977	37		11.1
		40	12.9	
		54		11.2
		88		8.4
		90	9.5	
		94		8.0
		123		7.7
		124	8.5	
		129		7.5
		132	8.0	
		136		5.6
		311		6.7
		312	8.6	
		318		8.3
		325		7.7
		328	8.6	
		333		8.3

Table B-1. (Continued)

Reservoir	Year	Date	Field Measurement	Laboratory Measurement
Watts Bar (continued)	1978	220	4.2	4.9
		221	4.6	
		227		4.6
	1979	121		7.9
		124	8.4	
		128		8.0
		344		8.8
		346	9.9	
		351		8.5
Fort Loudoun	1975	10		10.0
		14	10.2	
		15		9.8
		330		8.2
		336	12.1	
		337		9.1
	1976	75		9.2
		76	8.9	
		82		9.6
		314		8.6
		317	9.0	
		318		8.6
	1977	123		6.0
		130	7.6	
		137		5.8
		200		2.8
		202	2.6	
		206		2.5
	1979	92		8.3
		94	9.6	
		106		7.9
		317		7.0
		319	7.6	
		324		6.6

END

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