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TENNESSEE VALLEY AUTHORITY

Water Resources
Intern

A Comparison of Methods to Evaluate Reservoir Dissolved Oxygen Data

Average Cross-sectional Area
vs.
Time X Depth Integrations

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INTRODUCTION

My assignment as an undergraduate intern at Tennessee Valley authority, Chattanooga, TN, read:

"Assist with analysis and display of TVA reservoir vital signs monitoring data, and with the publication of technical reports associated with those projects. One aspect of that work will be to examine reservoir dissolved oxygen data to try to improve the method used to evaluate reservoir ecological health. The current method of integrating (time X depth) areas less than 2 mg/l needs to be compared with two other methods. Those methods use cross-sectional geometries at each sampling location to account for smaller proportional volumes in the bottoms of deeper reservoirs that often have lower dissolved oxygen levels."

The Tennessee Valley Authority operates over 40 reservoirs in the Tennessee valley region for a variety of uses, including water supply, recreation, flood control, and hydroelectric power. TVA views its stewardship responsibilities for these reservoirs as one of the agency's main reasons for existence. One of TVA's missions is "to make the Tennessee River the cleanest and most productive commercial river system in the United States by the year 2000," (Dycus and Meinert, 1993).

An important component in the achievement of this goal is a comprehensive, integrated water quality monitoring program. The

reservoir "vital signs" monitoring program began in 1990. One of its objectives is to provide basic information on the "health" or integrity of the aquatic ecosystem within each TVA reservoir. (Dycus and Meinert, 1993)

Vital Signs Monitoring uses five aquatic health indicators - - Dissolved Oxygen, chlorophyll-a, sediment quality, benthic macroinvertebrates, and fishes -- to evaluate each reservoir's overall condition. A rating scheme was developed for each indicator and then each reservoir is given an overall "grade" according to its ecological health. (Dycus and Meinert, 1993) This information is distributed to the public via a magazine-style publication, Riverpulse, (Attachment 1).

As described above, this study attempts to improve upon the method currently used in assessing the water column dissolved oxygen (DO).

All other projects that I contributed to this summer are summarized after the bibliography.

BACKGROUND

Oxygen is vital for life. For the fishes, insects, and zooplankton in the water column a certain amount of DO is necessary for survival. During the winter and spring seasons, a reservoir is normally well mixed and near-saturation concentrations of DO are available due to this mixing. However with the onset of the summer months (usually characterized by more available sunlight, warmer water temperatures, and lower streamflows) both thermal stratification and increased biological activity combine to produce a greater demand for the oxygen than is available, at the bottom of the water column. (Dycus and Meinert, 1993)

The present method TVA uses to evaluate DO in reservoirs considers oxygen concentrations in the water column (WCdo). Isopleths of DO concentrations versus depth and time are plotted for each location during the period when maximum thermal stratification and hypolimnetic anoxia would be expected to occur (April through September or October). This time is slightly different depending on the type of reservoir. Examples are shown in Figures 1 and 2, (Dycus and Meinert, 1993).

A concentration of 2 mg/l was selected as a level below which adverse impacts to benthic macroinvertebrate organisms and loss of habitat begin to occur. TVA's WCdo rating for each sample location is based on analysis of the percent of the time x depth profile that the concentration of DO was less than 2.0

Figure 1: Wilson Reservoir -- TRM 260.8
(Run - of - the - river reservoir)

Figure 2: Cherokee Reservoir -- HoRM 76.0
(Tributary, storage reservoir)

Time vs. Depth Plots of Dissolved Oxygen Concentrations

mg/L, according to the following criteria:

Percent of (time x depth) less than 2 mg/L -----	WCdo Rating for Sampling Location -----
<5%	(good)
>5% but <10%	(fair)
>10%	(poor)

Other adjustments are sometimes made in the rating system to incorporate state DO water quality criteria for fish and aquatic life into the evaluation. These are outlined in Dycus and Meinert, 1993.

This study attempts to improve upon the method for obtaining the WCdo (Water Column) rating by employing an alternative method. This method computes the cross-sectional area of a reservoir with $DO < 2$ mg/L. The monthly DO measurements made in the midchannel (maximum depth) at a sample location are assumed to be representative of the full width of the reservoir at the sampling location. The DO measurements are superimposed on the cross-section of the reservoir at the sampling location and cross-sectional areas are computed for the reservoir at that location and for the area with DO less than 2 mg/L. This method assumes that the water surface of the reservoir is flat.

PROCEDURE

The first step in this effort was an examination of 1992 Vital Signs data to find the dates when dissolved oxygen readings were less than 2 mg/L. During this search, the river mile of the sampling location, day, and month was recorded for each occurrence of low DO. Next, the water surface elevation of each river mile on that day and month was recorded. All further calculations were based on the actual lake elevations on that day and month in 1992.

Computation of Reservoir Cross-sectional Area

A spreadsheet was begun with columns A and B representing (at a given river mile) the distance from a surveyed reference point on the shoreline and the reservoir bottom elevation at each distance, respectively. A series of calculations in the spreadsheet were then developed to find the total cross-sectional area of the reservoir at the given river mile. This was accomplished by first finding the areas between adjacent sets of distances from the shore, then summing them for a total.

To find the area between each set, the difference between each bottom elevation and the water surface was calculated. This was occasionally complicated by the presence of islands, therefore an if/then statement was created. Next, the difference between each distance from the shoreline was taken. Once the

distances across and down were found, they were multiplied by each other to produce the area between each data set. These numbers were then summed for a total area. An example of these calculations is shown in Table 1.

Computation of Cross-sectional Area with DO <2 mg/L

The next goal was to determine the cross-sectional area of the reservoir in which the DO was less than 2 mg/L. I began by finding the elevation at which the monitored DO was first observed to be less than 2 mg/L. This required some conversion because those depths taken in the field are recorded in meters. Usually from that first elevation on to the bottom of the reservoir the DO was less than 2 mg/L (Figure 3), but sometimes there were low DO zones in the middle depths of the reservoir. Also, many times the bottom was rugged and this interfered with the calculation process. Examples of each of these is given below.

Case 1 -- Hypolimnetic DO<2 mg/L

If the DO<2 mg/L started at one elevation and ran to the bottom, (i.e.hypolimnion), equation 5.1 (shown in Figure 3) was used in column G (Table 2). This allowed for the rugged bottom, because if the elevation in column B was higher than the elevation at which the DO<2 started, a zero would be recorded. If not, it would be subtracted as was column C. Column G was then multiplied with column D as before and the products were summed to give the total area where the DO was less then 2 mg/L,

Table 1: Computation of Reservoir Cross-sectional Area

Boone Reservoir
RM 26.9

	A	B	C	D	E	F
1	17.51	1,383.00	0.00	0.00	0.00	0.00
2	18.51	1,382.00	1.00	1.00	1.00	1.00
3	20.21	1,381.00	2.00	1.70	3.40	5.91
4	21.52	1,380.00	3.00	1.31	3.93	9.84
.						
.						
28	41.53	1,367.00	16.00	1.36	21.74	212.52
29	42.89	1,366.00	17.00	1.36	23.10	235.63
30	44.08	1,365.12	17.88	1.19	21.27	256.89
31	44.28	1,365.00	18.00	0.20	3.56	260.45
32	45.86	1,364.00	19.00	1.59	30.16	290.62
.						
.						
207	741.13	1,380.00	3.00	4.75	14.25	36,098.84
208	746.18	1,381.00	2.00	5.05	10.10	36,108.94
209	751.23	1,382.00	1.00	5.05	5.05	36,113.98
210	756.28	1,383.00	0.00	5.05	0.00	36,113.98

Total Area (sqft)

Column A = Distance from Reference Point on the Shoreline
 Column B = Reservoir Bottom Elevation (MSL-Feet)
 at each distance

Column Ci = @IF(Bi<=1383*,1383*-Bi,0) 1.0
 Column Di = @ABS(Ai-(Ai-1)) 2.0
 Column Ei = (DixCi) 3.0
 Column Fi = (Ei+(Fi-1)) = Total Area of Reservoir 4.0

*where: 1383 is water surface elevation of reservoir

**Table 2: Computation of Cross-sectional Area
of DO<2 mg/L**

Boone Reservoir
RM 26.9

	A	B	C	D	E	F	G	H	I
1	17.51	1,383.00	0.00	0.00	0.00	0.00			
2	18.51	1,382.00	1.00	1.00	1.00	1.00			
3	20.21	1,381.00	2.00	1.70	3.40	5.91			
4	21.52	1,380.00	3.00	1.31	3.93	9.84			
.									
.									
28	41.53	1,367.00	16.00	1.36	21.74	212.52			
29	42.89	1,366.00	17.00	1.36	23.10	235.63	0.00	0.00	0.00
30	44.08	1,365.12	17.88	1.19	21.27	256.89	0.88	1.04	1.04
31	44.28	1,365.00	18.00	0.20	3.56	260.45	1.00	0.20	1.24
32	45.86	1,364.00	19.00	1.59	30.16	290.62	2.00	3.18	4.41
.									
184	648.92	1,365.00	18.00	4.36	78.49	35,147.56	1.00	4.36	5,789.70
185	653.28	1,366.00	17.00	4.36	74.13	35,221.69	0.00	0.00	5,789.70
.									
207	741.13	1,380.00	3.00	4.75	14.25	36,098.84			
208	746.18	1,381.00	2.00	5.05	10.10	36,108.94			
209	751.23	1,382.00	1.00	5.05	5.05	36,113.98			
210		1,383.00	0.00	5.05	0.00	36,113.98			

Total Area of
DO<2 mg/L, (sqft)

Column Gj = @IF(Bj<=1366*,1366*-Bj,0) 5.1

Column Hj = (GjxDj) 6.0

Column Ij = (Hj+(Ij-1)) = Total Area of DO<2 mg/L 7.0

*where: 1383 is water surface elevation of reservoir
1366 is elevation where DO is 2 mg/L
(See Figures for example)

column I (Table 2).

Case 2 -- Metalimnetic $DO < 2$ mg/L

If there was a zone of low DO at the middle depths, (i.e. metalimnion), equation 5.2, depicted in Figure 4, was used. In this illustration, the low DO zone begins at elevation 1375ft and extends down to elevation 1370ft. If the bottom elevation in column B fell between 1370 and 1375, it was subtracted as usual. If it was less than 1370, then the thickness of the low DO layer ($1370 - 1375 = 5$ ft) was recorded. This assumes a horizontal DO gradient across the reservoir as mentioned earlier. These numbers in column G were then multiplied by the length of each segment and the resulting areas summed.

Case 3 -- Bottom Penetration of Low Metalimnetic $DO < 2$ mg/L

On rare occasions, an underwater hill penetrated into the bottom of a mid-depth low DO zone. Equation 5.3 below Figure 5 was developed to deal with this situation. If the bottom elevation fell between 1370 and 1375, then it was subtracted as usual. If the bottom elevation was greater than 1375, then zero was recorded, to account for the hill extending through the low DO zone. If it is less than 1370, the difference between 1375 and 1370, again, was recorded to obtain the thickness of the zone. Table 2 shows a spreadsheet with columns G,H, and I added.

Often areas of $DO < 2$ reappeared at an elevation below the mid-depth low DO zone (Also Figure 5). In this case another set of three columns (J,K, and L) was developed in the same way as

Figure 3: Computation of Cross-sectional Area of DO<2 mg/L (Basic)

$$\text{Column Gj} = @IF(Bj \leq 1366^*, 1366^* - Bj, 0) \quad 5.1$$

*where: 1366 is elevation where DO is <@ mg/L

Figure 4: Computation of Cross-sectional Area of DO<2 mg/L when a Zone of Low DO Occurs in the Middle Depths of a Reservoir

$$\text{Column Gj} = @IF(Bj \geq 1370, 1375 - Bj, 1375 - 1370) \quad 5.2$$

*where: 1375 is the elevation where the low DO zone begins
1370 is the elevation where the low DO zone ends

Figure 5: Computation of Cross-sectional Area, When
Land Penetrates a Zone of Low DO

$$\text{Column Gj} = @IF(Bj >= 1370 \# AND \# Bj <= 1375, 1375 - Bj, \\ @IF(Bj >= 1375, 0, 1375 - 1370)) \quad 5.3$$

$$\text{Also, Column Jj} = @IF(Bj <= 1366, 1366 - Bj, 0) \quad 5.1$$

*where: 1375 is elevation where DO < 2 begins
1370 is elevation where low DO zone ends
1366 is elevation where DO < 2 begins again

columns G,H, and I, starting at the elevation of the top of that zone and using equation 5.1 in column J. The results of column L would be added to the preceding results of column I to obtain the total area $DO < 2$ mg/L.

RESULTS

This cross-sectional procedure was completed for all reservoirs where DO was observed to be less than 2 mg/L. These reservoirs are listed in Table 3. A table was developed including all water surface elevations, dates, total cross-sectional area of the reservoirs, and the percent cross-sectional area of the DO<2 mg/L. (Appendix A)

Values of DO<2 mg/L occurred in most reservoirs for more than one month in 1992. Therefore, for each month DO was less than 2 mg/L, calculations were made separately. When all the data was obtained for each reservoir river mile, the percentages were averaged and divided by six months (April-Sep.). This number then became the new WCdo rating to be used in the formula for the oxygen evaluation of a reservoir as previously described in BACKGROUND.

DISCUSSION

Shown in Figure 6, the new percentages (average cross-sectional areas) of DO<2 mg/L were plotted against the old percentages (time X depth integrations) of DO<2 mg/L. As predicted, there was a definite correlation between the two ($r=0.91$). Regression Analysis was performed to determine correlation numerically (Figure 7).

Those reservoirs with greatest differences between new and old methods are as follows:

Figure 6:

A Comparison of the Old and New % Areas
in Reservoirs where DO is <2mg/l

Figure 7:
Regression of New %<2DO and Old %<2DO

Reservoir RM	Old (%)	New (%)
-----	-----	-----
Tellico RM0.5	19.38	4.58
Beech RM35.6	30.66	37.92
Watauga RM44.8	10.26	3.01
Nottely RM31.0	9.68	3.40
Tims Ford RM149.7	34.21	22.46
S.Holston RM61.8	19.22	11.13
S.Holston RM51.6	13.24	6.17

Note in Figure 7, Tellico and Beech Reservoirs fell outside the 95% prediction interval for new data. Tellico Reservoir was sampled at river mile 0.5. Here the reservoir has a very deep, narrow portion where the low DO is confined. Then the reservoir bottom comes up sharply to form its basin (Figure 8). Beech, on the other hand, is directly opposite. The sampling station on this reservoir is located at RM36.5. The reservoir is only 30ft deep, but around 1700ft wide (Figure 9). Other reservoirs noted to be affected by the new method were: Watauga RM44.8, Nottely RM31.0, S.Holston RM61.8 and RM51.6, and Tims Ford. These are illustrated in Figures 8-14 with the locations of their low DO. Each has a unique characteristic, causing them to be affected by the new method.

CONCLUSIONS AND RECOMMENDATIONS

As shown in Figures 8-14, each new percentage affected by the new method is more representative of a reservoir with a narrow portion(s). This method tends to improve the DO ratings

Figure 8

Figure 9

Beech Reservoir RM35.6

Figure10

Watauga Reservoir
RM44.8

Figure11

Nottely Reservoir
RM31.0

Figure12

Tims Ford Reservoir
RM149.7

Figure 13

Figure 14

in deep, narrow reservoirs because the amount of water containing the low DO is small compared to the total cross-sectional area which contains better DO concentrations. In wider, shallower reservoirs (i.e. Beech), this method tends to lower the DO rating. In respect to these conclusions, this method would probably be a bit more accurate than the currently used method.

However, this method is extremely time consuming and sometimes tedious.

Therefore, it must be determined as to whether the smallest degree of accuracy is worth the extra time.

REFERENCES

Dycus, Donald and Dennis Meinert. 1993. *Monitoring and Evaluation of Aquatic Resource Health and use Suitability in Tennessee Valley Authority Reservoirs*. TVA Water Resources, Chattanooga, TN.

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