Reaeration Tests, Enid Lake Outlet Works

Charles H. Tate, Jr.
Research Hydraulic Engineer
Waterways Experiment Station
U. S. Army Corps of Engineers
Vicksburg, Mississippi

INTRODUCTION

Properly designed hydraulic structures can enhance the quality of water released from lakes; conversely, improperly designed structures may release flow supersaturated with nitrogen or void of oxygen with possible adverse effects on the environment. As a result, the U. S. Army Corps of Engineers has found it imperative to acquire prototype and hydraulic model data from which predictive techniques can be developed to design hydraulic structures.

The direction of this research effort at the Waterways Experiment Station (WES) has been to develop a method of measuring the gas transfer that occurs in prototype structures and in physical hydraulic models. Eventually the information obtained using the method will be used to determine a model to prototype scale relation. Additionally, predictive techniques will be evaluated to facilitate preconstruction design for gas transfer.

As a part of the above effort, measurements have been taken at Enid Lake using the radioactive gas tracer technique developed by Dr. E. C. Tsivoglou. This technique was selected several years ago for evaluation in physical model tests based on measurement precision, dosing method, and previous use. In 1977, the method was successfully demonstrated in a 1:20-scale spillway model by WES personnel and Dr. Tsivoglou. Techniques similar to those used in the model study were used at Enid Lake during August 1978 and the results of the prototype tests are the subject of this paper.

PURPOSE AND SCOPE OF STUDY

The primary objective of the Enid Lake tests was to demonstrate that the radioactive gas tracer technique can be applied to reservoir outlet works and to develop the techniques to collect tracer samples in and around the outlet structure. As a result, the gas transfer characteristics of the Enid Lake outlet works would be available for comparison with model data to determine the scaling relations for the technique.

Dr. Tsivoglou was placed under contract with WES to assist WES personnel in the performance of the Enid Lake tests and to provide the laboratory analysis of the samples. In addition, Dr. Tsivoglou's radioactive materials license was used to conduct the tests.

DESCRIPTION OF PROTOTYPE

Enid Lake is on the Yocona River approximately one-half mile east of Interstate 55 in north Mississippi (Figure 1). Although Enid Dam is part of a comprehensive flood control plan for the Yazoo River Basin above the Mississippi River backwater area, it is used extensively for recreation. The dam is an earth fill structure 8400 ft long with a crest elevation of 293.0 ft, msl. From a 410-ft-wide base, the dam rises 85 ft to the crest which supports a 2-lane, asphalt paved road. The outlet structure is

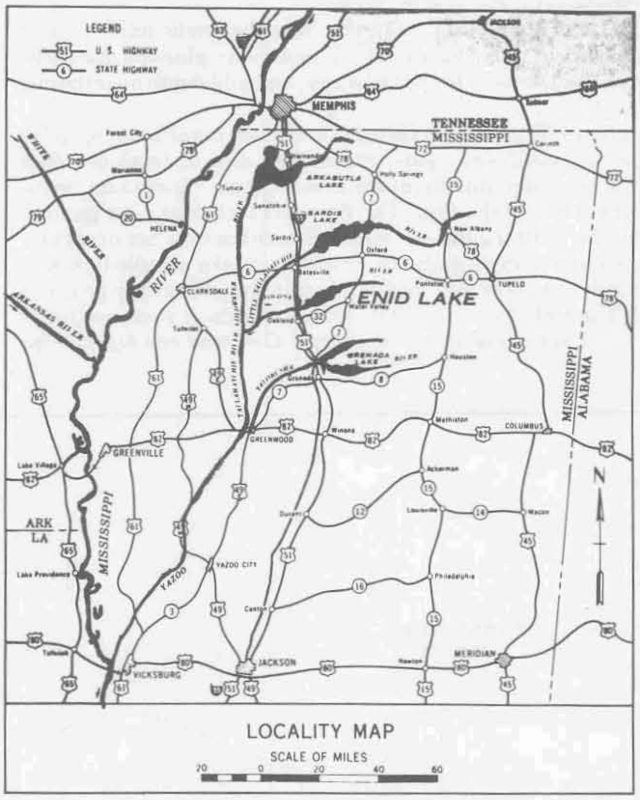

Figure 1

located near the north abutment. Two 8-ft-wide by 15-ft-high service gates regulate the release flow. Each gate releases flow into an 11-ft-diameter concrete conduit which passes through the base of the dam and discharges into one side of a separated stilling basin. The spillway is a concrete paved weir located in the north abutment and designed to pass excessive flood flows without endangering the dam.

TEST AND RESULTS

In order to test the Enid Lake outlet structure the flow was "instantaneously" dosed upstream of the structure with a point dose. The dose contained three tracing elements, two of which are radioactive. Krypton-85 (Kr-85) as a fully dissolved gas in water is the radioactive tracer used to measure the gas transfer between the water and the atmosphere. The efflux of Kr-85 from the water is relatable to the influx of atmospheric gases to the water.

Tritium (H-3) as tritiated water molecules is the other radioactive tracer and is used to measure the dispersion of the dose in the water. The ratio of the radioactive tracers in the collected samples is used to determine the gas transfer rate in the test section. Rhodamine-wt dye is the third tracing element and is used to indicate the presence of the radioative tracers at the sampling stations.

At Enid Lake the dose bottle was broken underwater using an impact bottle breaker. Samples were collected when rhodamine-wt dye was observed at the sample stations. Samples from near the peak dye concentration were analyzed using a liquid scintillation counter to determine the Kr-85 and H-3 concentrations.

Additional information on the tracer technique can be found in "Proceedings of a Symposium on Direct Tracer Measurement of the Reaeration Capacity of Streams and Estuaries, U. S. Environmental Protection Agency."

The four sampling stations for the radioactive tracer measurements were located at the emergency gate slot, the outlet portal, the entrance to the tailwater, and mid-depth over the end sill.

Station 1 (Figure 2) consisted of an intake manifold suspended below the emergency gate. Streamline and undeveloped flow effects made a manifold intake necessary in order to sample the dosed volume of the flow. The flow was turbulent after passing under the control gate, and manifold intakes were not necessary at the other sample stations. From the intake sample flow was pumped to a collection location inside the emergency gate wet well. The techniques used for sample collection were similar at the other sampling stations. Sample flow was equally divided into a number of individual lines with one line supplying flow to a flow-through fluorometer. The remaining lines were used to supply flow to sample bottles. Because the flow had not been exposed to the atmosphere, the samples from Station 1 were used to verify the tracer ratios in the dose. Sample flow was drawn from the bottom of the conduit at Station 2. Using the results from this location and the initial tracer ratios the gas transfer in the conduit was determined.

The stilling basin apron at Enid is different from most silling basins in that the apron is stepped rather than following a parabolic trajectory. This was done to conserve forming costs. Consequently, the intake for Station 3 was located on one of the steps just below the tailwater at the toe of the hydraulic jump. This allowed the effect of the stepped apron to be isolated from the total effect of the stilling basin.

Supported by an innertube the intake at Station 4 was located at mid-depth over the end sill of the stilling basin and in the main portion of the flow. After mixing in the stilling basin, the dose dispersed such that only one sample line was necessary at this station.

Results of the tests are summarized in Figure 3 and on Page 2 of the Appendix. Although several problems occurred during the testing program the major problem involved Station 3. After Dose A the intake for Station 3 was pulled loose from its mounting and provided sample flow from outside the main portion of the flow. Consequently Doses B, C, and D are analyzed for a test reach from Station 2 to Station 4.

Figure 3 shows the average Kr-85 gas loss per test section. Doses A through D (100 cfs) lost an average of 65.1 percent of the

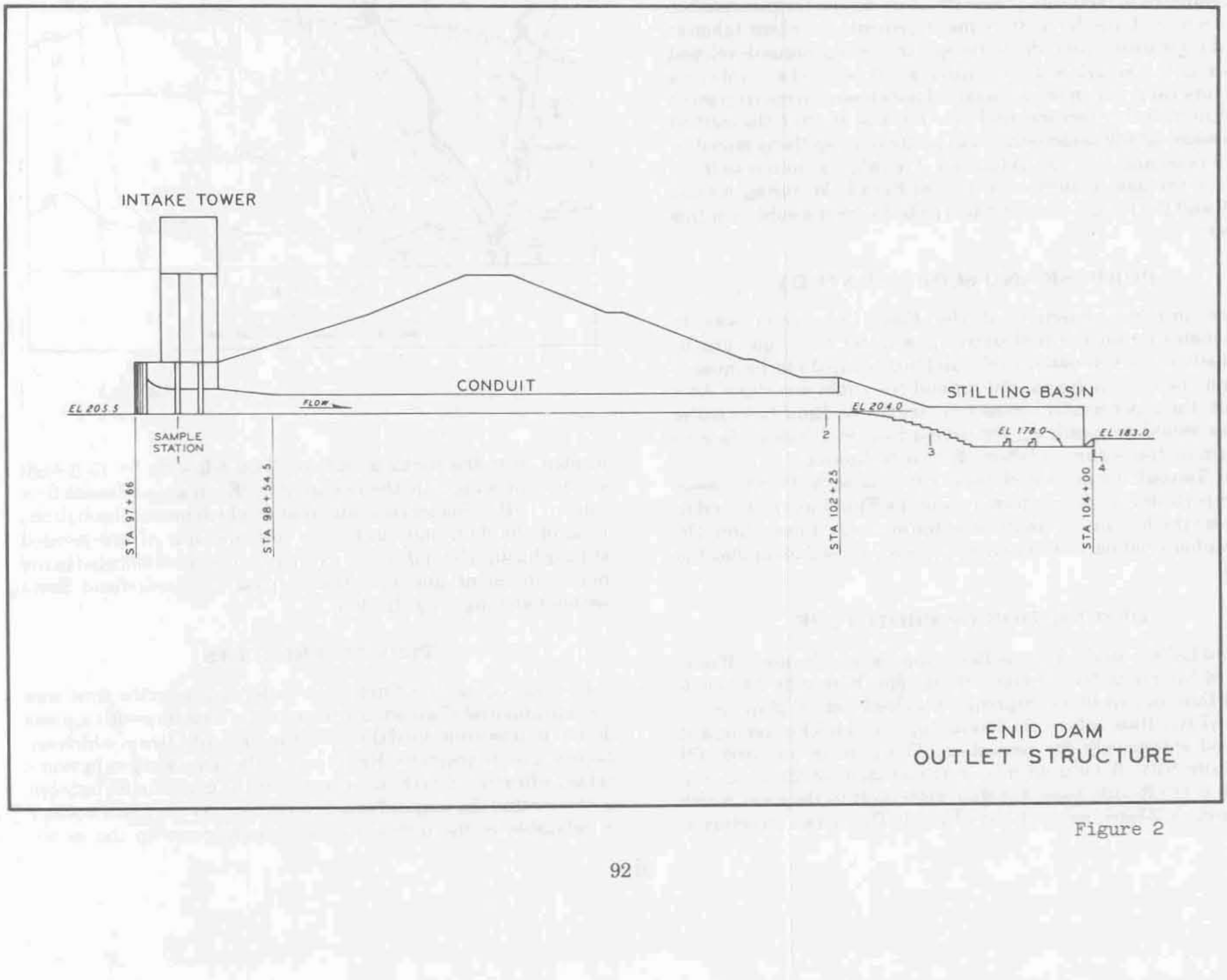

Figure 2

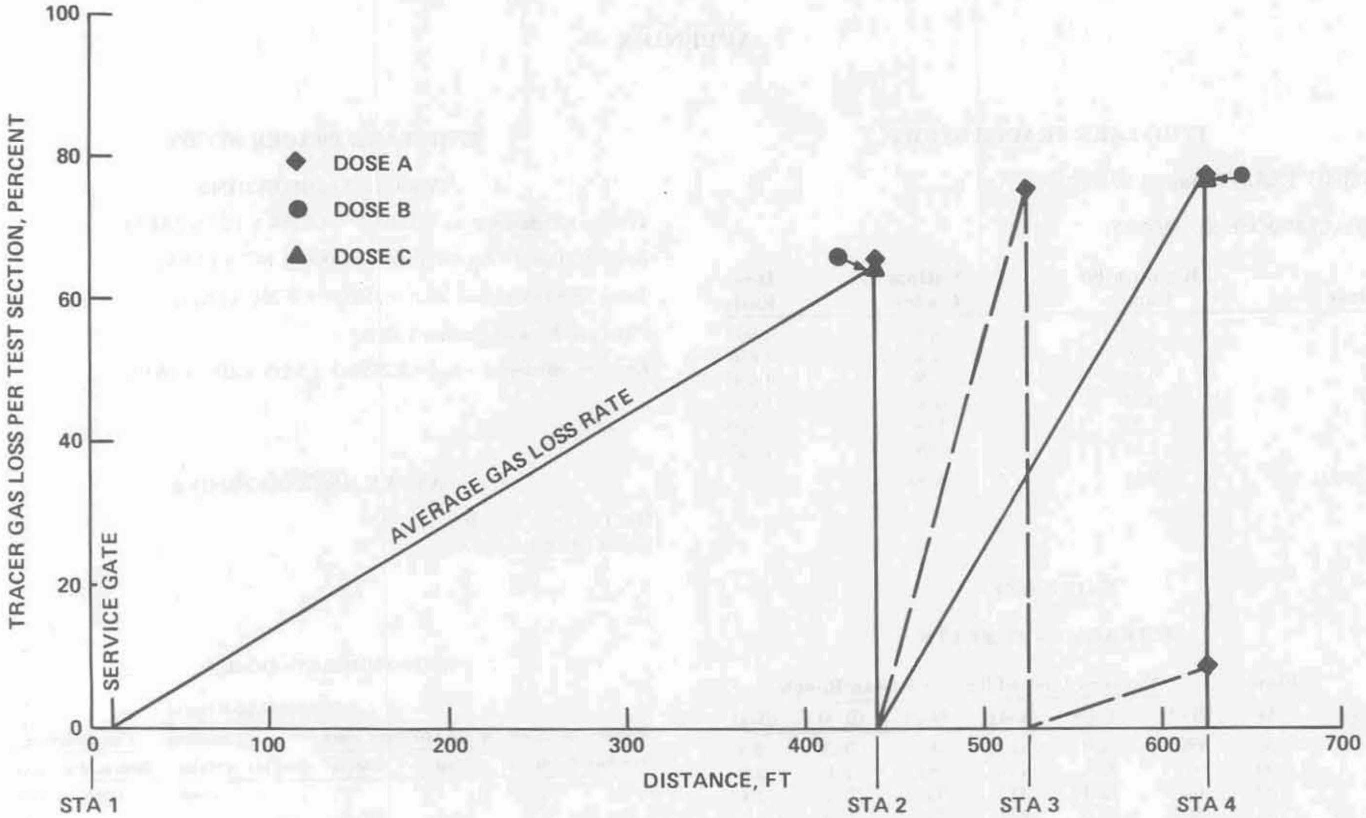

Figure 3

Kr-85 gas between Station 1 and Station 2. Of the remaining tracer gas, 77.9 percent was transferred to the atmosphere between Stations 2 and 4. Dose A indicates that most of the transfer between Stations 2 and 4 occurs prior to entering the tailwater at Station 3. The total tracer gas loss for Doses A through D averaged 92.3 percent. This relates to a potential for satisfying 95.4 percent of the DO deficit at Station 1 by methods described in the appendix.

Doses E and F (200 cfs) exhibited an average total tracer gas loss of 88.2 percent. This relates to a potential for satisfying 92.4 percent of the DO deficit at Station 1. Power failure and equipment malfunctions allowed samples for Doses E and F to be collected at Stations 3 and 4 only with Station 3 being suspect.

Due to equipment problems, only six doses were released at Enid instead of the eight scheduled. Plans exist to return to Enid Lake and use the remaining doses at higher flows. It has been demonstrated that tracer samples can be collected in hydraulic structures and that small changes in the gas transfer can be detected.

Since the completion of the Enid Lake tests, several changes have taken place regarding equipment and techniques. These changes involve increasing the dependability of the testing equipment and reducing the power requirements for field application. Most of the changes have been field tested and appear to work well.

Acknowledgements

The radioactive tracer tests at Enid Lake were coordinated with the Nuclear Regulatory Commission, the Division of Radiological Health of the Mississippi State Board of Health, and the Air and Water Pollution Control Commission. Permission to conduct the tests at Enid Lake was obtained from the District Engineer, Vicksburg District, U. S. Army Corps of Engineers, with the point of contact at the District office being Mr. Bob Palermo, Chief of the Reservoir Regulation Branch. Throughout the effort at Enid Lake the local staff was extremely helpful with information and assistance.

APPENDIX

ENID LAKE TRACER STUDY

STUDY PERIOD: August 20-25, 1978

TRACER DOSE SUMMARY:

Dose	Krypton-85 Curies	Tritium Curies	Dose Ratio
A	0.80	0.50	1.600
B	0.80	0.50	1.600
C	0.80	0.50	1.600
D	0.80	0.50	1.600
E	1.52	1.00	1.520
F	1.52	1.00	1.520
Totals:	6.24	4.00	

ENID LAKE

SUMMARY OF RESULTS

Dose	Flow, cfs	Percent Loss of Tracer Gas in Reach (1-2)	(1-3)	(1-4)	(2-3)	(2-4)	(3-4)
A	100	66.3	92.0	92.7	76.2	78.3	8.9
B	100	nd	92.4	92.1	nd	nd	-3.3
C	100	64.3	92.4	92.2	78.6	78.1	-2.4
D	100	64.6	92.5	92.0	78.7	77.3	-6.6
	Mean:	65.1	92.3	92.3	77.8	77.9	-0.9
E	200	nd	88.0	87.6	nd	nd	-3.5
F	200	nd	88.5	88.7	nd	nd	1.3
	Mean:	nd	88.3	88.2	nd	nd	-1.1

nd: not determined

KRYPTON: OXYGEN RELATIONSHIPS

From $R_2 = R_1 e^{-K_{kr} t}$ where R = Kr-85:H-3 ratio

and $D_2 = D_1 e^{-K_{ox} t}$ where D = DO deficit

and $K_{kr} = 0.83 K_{ox}$

it follows that

$$\ln \frac{D_2}{D_1} = \frac{\ln \frac{R_2}{R_1}}{0.83} \qquad (1)$$

at a specific temperature, and in a system where there is no significant DO source or sink except reaeration.

Under such circumstances, it is not necessary to evaluate the reaction rate ceofficients, K_{kr} and K_{ox}, in order to predict the downstream DO from the observed tracer data and the upstream DO. Equation (1) is sufficient.

Examples:

Reach (1-2) $(R_2/R_1)_{ave} = (1 - 0.651) = 0.349$

and $D_2 = (0.281) \times D_1$

or, 72 percent of the DO deficit present at Station 1 will be satisfied at Station 2, the end of the conduit, at the prevailing temperature in our study and 100 cfs.

Reach (1-4) $(R_4/R_1)_{ave} = (1 - 0.923) = 0.077)$

and $D_4 = (0.046) \times D_1$

ENID LAKE TRACER STUDY

FINAL CALIBRATIONS

Tritium efficiency = $e_H = 0.1005 + 1.1784 \times 10^{-6} \times (AES)$

Kr-85 Spillover = $Sp = 0.0566 - 2.2000 \times 10^{-7} \times (AES)$

Total Kr-85 Counts = $\Sigma Kr = 35{,}600 + 0.220 \times (AES)$

From analysis of Station 1 data:

Krypton efficiency = $e_{Kr} = 0.2559 + 1.5835 \times 10^{-6} \times$ (AES

SAMPLE BACKGROUND a

Red Channel: 149.89
Green Channel: 226.89

DATA SUMMARY - DOSE A

Station Number	Sample Number	Mean 10-Min Count Red	Green	Kr-85:H-3 Ratio Sample	Station Mean	Gas Fraction Remaining	Lost
1	ns	-	-	-	1.600	1.000	0.000
2	1	8,831	8,329	0.515			
	2	7,875	7,864	0.554	0.539	0.337	0.663
	4	6,896	6,915	0.548			
3	3	2,956	872	0.123			
	4	3,493	1,022	0.128	0.128	0.080	0.920
	5	3,393	1,031	0.133			
4	11	2,440	736	0.119			
	12	2,424	733	0.120	0.117	0.073	0.927
	13	2,451	703	0.111			

ns: this station not sampled
a: dose ratio determined at Georgia Tech

DATA SUMMARY - DOSE B

Station Number	Sample Number	Mean 10-Min Count Red	Green	Kr-85:H-3 Ratio Sample	Station Mean	Gas Fraction Remaining	Lost
1	ns	-	-	-	1.600	1.000	0.000
2	ns	-	-	-	-	-	-
3	2	3,214	913	0.120			
	3	3,294	947	0.123	0.122	0.076	0.924
	4	3,163	921	0.124			
4	1	5,073	1,366	0.124			
	2	4,958	1,402	0.131	0.126	0.079	0.921
	3	4,880	1,317	0.124			

ns: this station not sampled
a: dose ratio determined at Georgia Tech
b: sample counts all near background - station deleted

a: determined from the sample taken for Doses A and B

DATA SUMMARY - DOSE C

Station Number	Sample Number	Mean 10-Min Count Red	Mean 10-Min Count Green	Kr-85:H-3 Ratio Sample	Kr-85:H-3 Ratio Station Mean	Gas Fraction Remaining	Gas Fraction Lost
1	3	181,272	427,924	1.377			
	4	207,366	543,249	1.544	1.530	1.000	0.000
	5	131,825	369,635	1.668			
2	2	54,195	56,173	0.573			
	3	51,225	49,113	0.528	0.546	0.357	0.643
	4	43,940	42,849	0.537			
3	2	2,247	681	0.116			
	3	2,908	844	0.120	0.117	0.076	0.924
	4	2,682	772	0.115			
4	2	4,887	1,244	0.115			
	3	3,478	949	0.116	0.120	0.078	0.922
	4	1,736	607	0.128			

DATA SUMMARY - DOSE D

Station Number	Sample Number	Mean 10-Min Count Red	Mean 10-Min Count Green	Kr-85:H-3 Ratio Sample	Kr-85:H-3 Ratio Station Mean	Gas Fraction Remaining	Gas Fraction Lost
1	6	98,066	259,521	1.566			
	7	93,901	262,703	1.667	1.672	1.000	0.000
	8	90,819	269,952	1.783			
2	1	137,245	147,173	0.594			
	2	98,934	104,712	0.588	0.593	0.354	0.646
	3	52,594	56,669	0.596			
3	2	2,899	877	0.127			
	3	2,915	871	0.125	0.126	0.075	0.925
	4	2,411	760	0.126			
4	3	4,708	1,427	0.141			
	4	4,207	1,180	0.126	0.134	0.080	0.920
	5	2,996	944	0.135			

DATA SUMMARY - DOSE E

Station Number	Sample Number	Mean 10-Min Count Red	Mean 10-Min Count Green	Kr-85:H-3 Ratio Sample	Kr-85:H-3 Ratio Station Mean	Gas Fraction Remaining	Gas Fraction Lost
1	-	-	-	-	1.520	1.000	0.000
2	ns	-	-	-	-	-	-
3	4	2,384	1,061	0.201			
	5	3,390	1,315	0.181			
	6	3,514	1,400	0.188	0.182	0.120	0.880
	7	3,590	1,324	0.172			
	8	3,405	1,255	0.169			
4	2	4,106	1,704	0.201			
	3	4,039	1,678	0.201			
	4	3,404	1,385	0.191	0.188	0.124	0.876
	6	3,333	1,273	0.177			
	7	3,390	1,263	0.172			

ns: this station not sampled
a: dose ratio determined at Georgia Tech

DATA SUMMARY - DOSE F

Station Number	Sample Number	Mean 10-Min Count Red	Mean 10-Min Count Green	Kr-85:H-3 Ratio Sample	Kr-85:H-3 Ratio Station Mean	Gas Fraction Remaining	Gas Fraction Lost
1	ns	-	-	-	1.520	1.000	0.000
2	ns	-	-	-	-	-	-
3	4	3,272	1,211	0.170			
	5	4,228	1,598	0.181			
	6	4,269	1,533	0.170	0.174	0.115	0.885
	7	4,138	1,500	0.172			
	8	4,251	1,592	0.180			
4	4	5,751	2,046	0.175			
	5	4,748	1,641	0.166			
	6	4,408	1,580	0.171	0.172	0.113	0.887
	7	3,892	1,456	0.177			
	8	3,159	1,188	0.172			

ns: this station not sampled
a: dose ratio determined at Georgia Tech