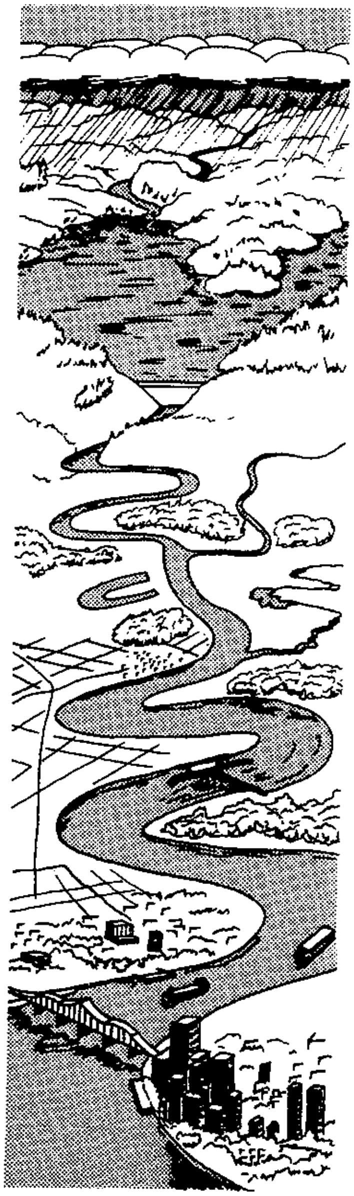
US Army Corps of Engineers
Waterways Experiment Station



WOTS/ Water Operations Technical Support

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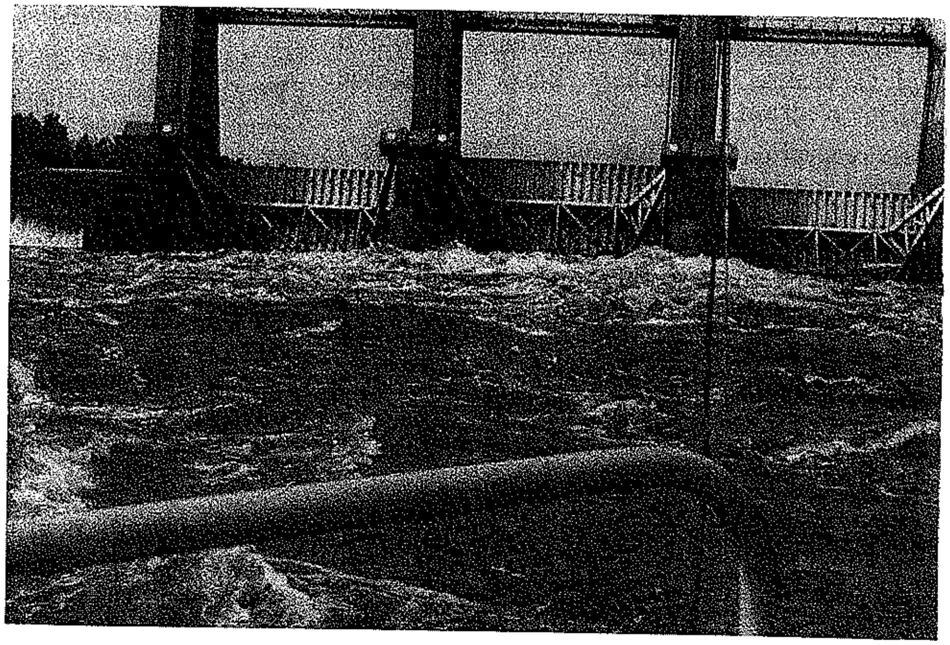

Columbia Lock and Dam, Ouachita River, Louisiana; three tainter gates on low-head spillway with accompanying fixed-crest overflow weir

Reaeration at Low-Head Gated Structures; Preliminary Results

by
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Reaeration or dissolved oxygen (DO) uptake at hydraulic structures can be a major source of water-quality maintenance or improvement in our Nation's inland waters. For this reason, understanding the reaeration characteristics of various hydraulic structures is important. For example, understanding the reaeration properties of a hydropower facility is essential for evaluating potential impacts of proposed hydropower installations. The same is true for other types of hydraulic structures, such as gated sills, gated spillways, gated conduits, or overflow weirs. The capability to compare the characteristics of the different structures is required if one structure is proposed to replace another, for example, hydropower retrofit into a spillway or gated conduit. Further, the effects of structure operations on release DO concentrations must be identified to permit selected operational changes for enhancement of in-river DO.

In the Environmental and Water Quality Operational Studies (EWQOS) Research Program, gated-conduit outlet works were analyzed on the basis of existing dissolved oxygen data (Wilhelms and Smith 1981) and specifically tested (Tate 1982) to describe their gas-transfer characteristics. Navigation locks were also tested (Wilhelms 1985) to determine the impact that their operations could potentially have on downstream water quality. Several alternatives for improving the release DO of high-head hydropower facilities were also identified (Bohac and others 1983) and tested (Wilhelms and others 1987) during the EWQOS program.

Past reaeration work has focused on relatively high-head projects, resulting in a shortfall in understanding the gas-transfer characteristics of low-head projects. This article presents preliminary results of an effort to study reaeration at low-head gated structures, as part of the ongoing Water Quality Research Program and with support from several field offices.

Objectives

The objectives of this research effort are to: characterize reaeration at low-head projects, identify and develop methods for improving the DO content of releases from these projects, and provide predictive tools and guidance for evaluating the effectiveness of various alternatives for release improvement.

The approach taken in this research effort was to initially survey Corps of Engineers' (CE) district offices (FOAs) to identify the number and location of low-head hydropower facilities. Simultaneously, selected field offices were contacted to help identify specific problems and potential solutions most often encountered at low-head projects. Based on this information, candidate sites for field tests would be selected. Through a coordinated effort with district offices, short-term intensive studies at these sites would provide a data base for developing and verifying mathematical descriptions of reaeration at low-head structures. With an understanding of the existing reaeration processes, alternative methods for improving release DO would be developed and demonstrated in conjunction with one or more FOAs.

Preliminary Results

Survey results. Seven of the CE divisions in the continental United States responded to the initial survey concerning low-head hydropower projects. Low-head, in this context, refers to the type of turbine employed at the facility. Kaplan or propeller-type turbines, including tube and bulb turbines, are considered low-head turbines. Thirty-seven existing hydropower projects in 14 CE districts were identified. Most of these were Federally owned, but at some CE flood-control or navigation projects, a private entity or local government agency may own the hydropower facility. Following the survey, several CE districts identified projects where non-Federal developers have proposed the retrofit installation of hydropower.

As expected, discussions with individuals at FOAs confirmed that release DO was the most common water-quality concern related to low-head structures. Specific problems related to DO included (1) no capability to predict release DO (effects of reaeration) from low-head structure, and thus, (2) no capability to evaluate the effects of hydropower retrofit, (3) no capability to address the impact of multiple hydropower retrofits on one river system, (4) no guidance on the impacts of operational changes on release DO, and (5) no guidance on alternatives to improve release DO from low-head hydropower and nonhydropower projects.

Field tests. As discussed previously, short-term field tests are necessary for developing an understanding of the physical processes that govern reaeration. These studies provide controlled evaluations of the hydraulic and geometric parameters that affect oxygen transfer. In these tests, the prototype structures become the laboratory for observations of gas transfer, which can be used to understand the relationships between reaeration and the existing hydraulic and geometric conditions. Ultimately, these observations will lead to the development of a mathematical description of these relationships.

Tsivoglou and Wallace (1972) showed that reaeration in streams is a function of the energy loss in a stream reach. Using this concept, Wilhelms and Smith (1981) developed a relationship describing reaeration in gated-conduit outlet structures as a function of the head loss through the structure. For low-sill, high-tailwater structures--typical of low-head navigation spillways--downstream submergence of the discharge must also be considered. Conceptually, gas transfer should decrease as tailwater submergence increases. Further, as will be shown, reaeration at a structure is influenced by the discharge per unit length of structure. Thus, head loss Δh, submergence s (Figure 1), and unit discharge significantly influence reaeration at low-head spillways.

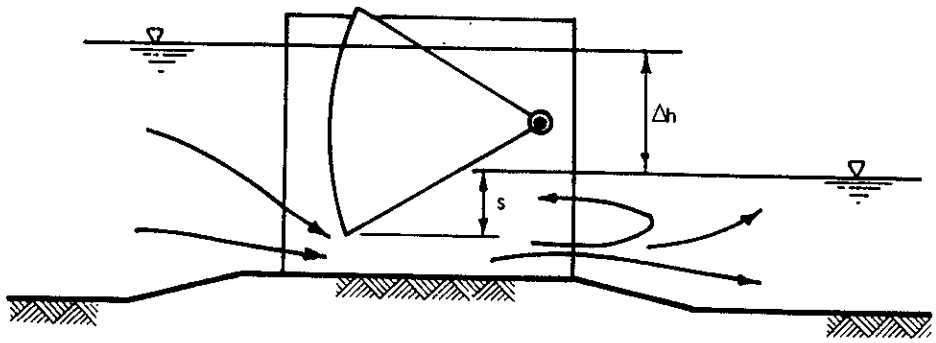


Figure 1. Definition sketch

In cooperation with the US Army Engineer District, Vicksburg, oxygen-uptake tests were conducted at three low-head spillways on the Ouachita and Red Rivers. Preliminary analysis indicated that substantially more reaeration was occurring at Red River Lock and Dam 1 (RR1), particularly for the higher discharges tested, than at either Columbia or Jonesville Locks and Dams (Figure 2). A review of their designs indicated that baffle blocks had been included in the stilling basin design on RR1, but were not part of the stilling basins at Columbia or Jonesville. It was concluded that the baffle blocks caused the additional reaeration. Because of this dissimilarity and the resulting difference in hydraulic action in the stilling basin, these structures were not grouped together in a single analysis. The remaining discussion includes only data from the Columbia and Jonesville structures.

Because gas transfer is affected by ambient water temperature, the observed oxygen uptake data were adjusted (Tsivoglou and Wallace 1972) to reflect a 20° Celsius (C) water temperature. A regression analysis was performed using the adjusted data as the dependent variable and head loss Δh, submergence, and unit discharge as independent variables. The mathematical description took the form

$$\frac{D_d}{D_u} = \frac{C_s - C_d}{C_s - C_u} = \exp\left(-a_{20}\frac{\Delta hq}{s} + b_{20}\right)$$

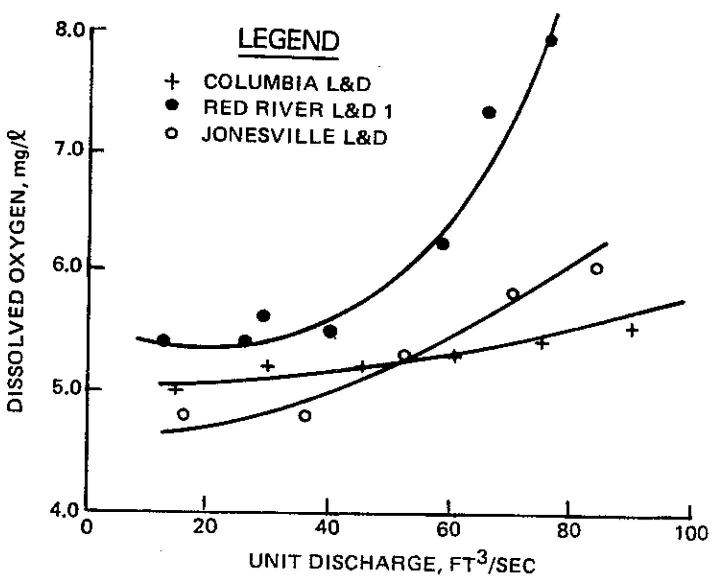
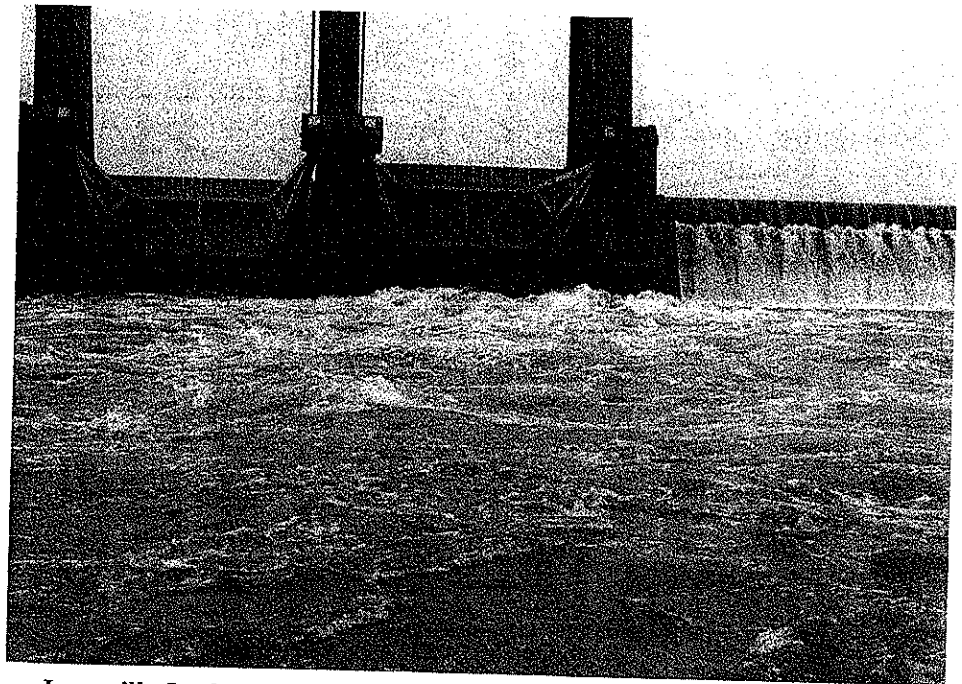
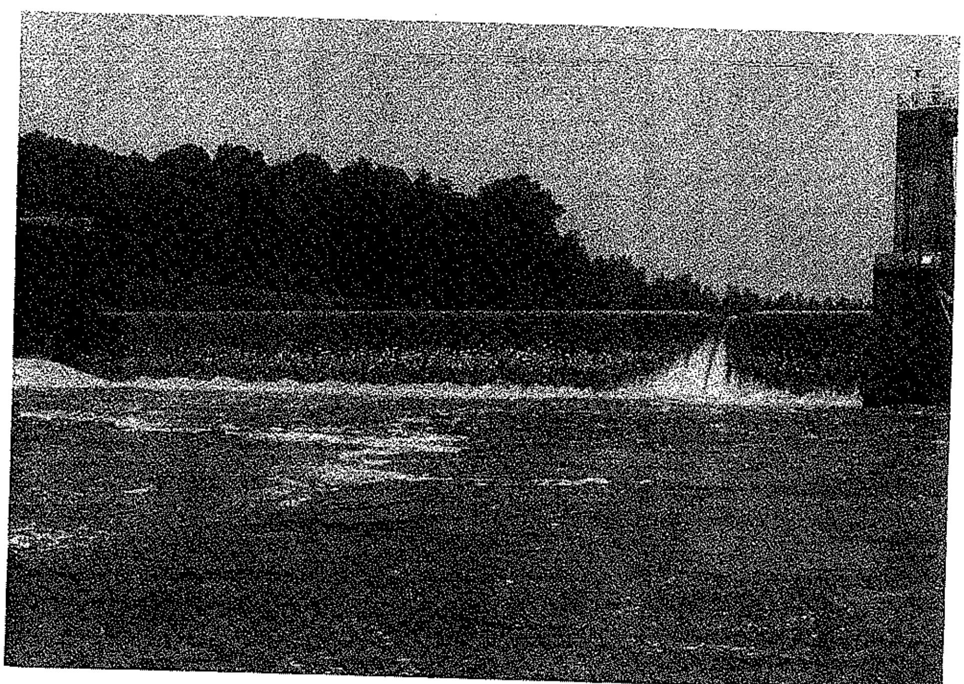


Figure 2. Release dissolved oxygen versus release flow rate



Jonesville Lock and Dam, Ouachita River, Louisiana; five tainter gates with variable crest overflow weir



Overflow weir at Columbia Lock and Dam, Ouachita River, Louisiana; good aerator where

D_d, D_u = downstream and upstream DO deficits, respectively, mg/ℓ

C_s = saturation concentration for ambient water temperature, mg/ℓ

C_d, C_u = downstream and upstream DO concentrations, respectively, mg/ℓ

a_{20}, b_{20} = regression coefficients for 20°C water temperature, sec/ft^3 and dimensionless, respectively

Δh = head loss through structure or difference in pool and tailwater elevations at structure, ft

q = unit discharge through gates, ft^3/sec/ft

s = gate lip submergence, ft

Results of the regression analysis indicated a value for a_{20} of 0.000797 with a value for the regression coefficient b_{20} of −0.188. Analysis of variance for the regression indicated that about 70 percent of the data variation (R-squared = 0.70) was explained with this description. Figure 3 shows a semi-log plot of the data and regression equation.

This relationship can likely be used to evaluate the reaeration at structures similar to those used in this analysis. The ranges of the variables that can be used have limitations, however, in the description because of its mathematical form. For example, submergence cannot equal 0.0, since the quotient in the exponent of the above equation would be undefined. Thus, an added recommendation would be to limit the range of s to values greater than 1.0 or 2.0 feet.

In addition to the reaeration at the spillways of the Columbia and Jonesville projects, significant oxygen uptake occurred at their overflow weirs. DO uptakes of about 3 mg/ℓ and 2.5 mg/ℓ were measured at the Columbia and Jonesville overflow weirs, respectively. This resulted in the downstream DO saturation levels ranging from about 85 to 95 percent. Generally, the overflow weirs aerated the discharge much more effectively than the low-sill spillway. If operationally feasible, improved release DO could be achieved by passing more discharge over the weirs.

Recommendations

Field observations lead to two operational recommendations to improve release DO: (1) overflow weir discharge should be maximized relative to discharge through the low-sill spillway and (2) the unit (single-gate) discharge should be maximized. However, for any of these operations, hydraulic feasibility must be considered, since undesirable flow conditions may occur in the energy dissipator for unequal gate operations. Further, limits may occur in the effectiveness of these operational alternatives as discharge becomes very large. Additional field testing and data analysis are planned to further the understanding of reaeration through gated structures as well as overflow weirs.

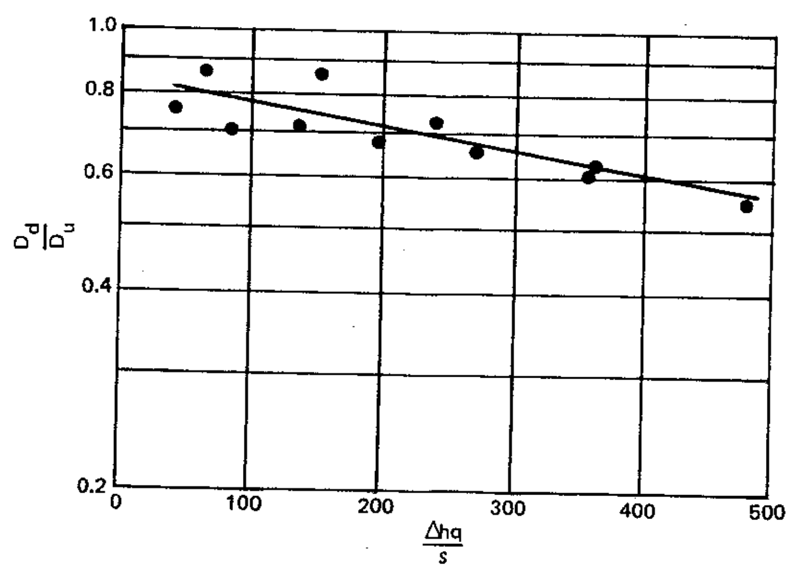


Figure 3. Deficit ratio versus combination of key parameters

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Pilot Study to Evaluate the Corps' Interlaboratory Testing Program for Chemical Analysis

by
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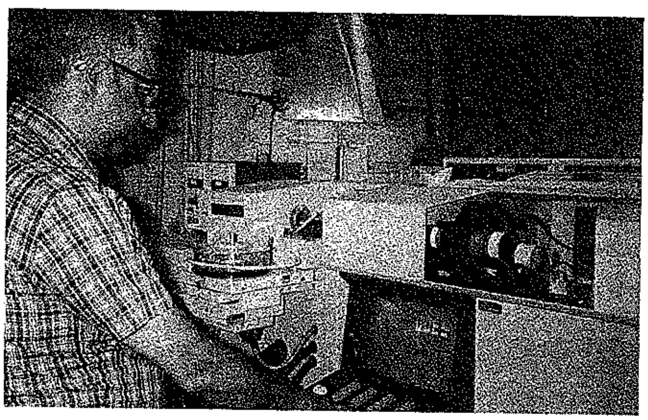


Analyzing samples for arsenic using a Zeeman atomic absorption spectrometer

A pilot study was conducted to evaluate an interlaboratory quality-assurance testing program being initiated by the Corps of Engineers for the eight division laboratories. Purposes of the program include evaluating laboratory performance, discovering analytical problems in the laboratories, correcting any apparent problems, and giving validity to analytical data produced by the laboratories. A well operated interlaboratory testing program will ensure that each participant is provided a critical evaluation of the performance of his laboratory, the agency is informed of expected analytical performance, and the data can be used to fulfill regulatory requirements for acceptable quality-assurance testing.

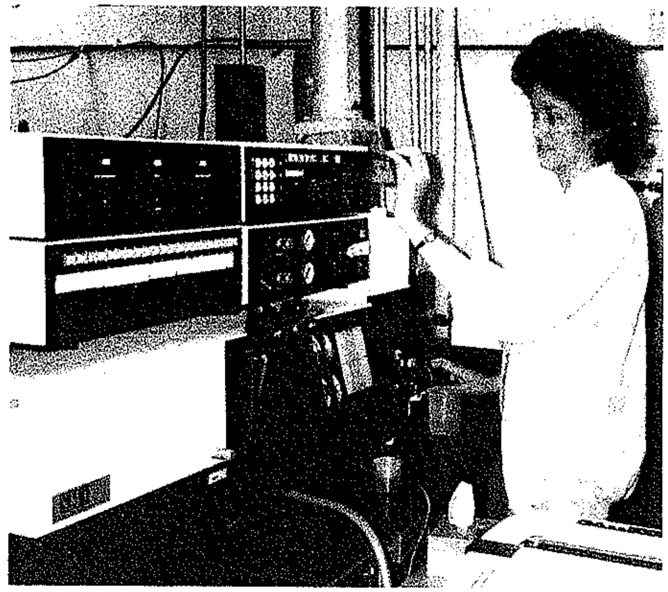
Testing Program

Because instrumentation and personnel capabilities varied among laboratories, some variations in the analytical procedures were expected. However, only methods widely accepted by agencies such as the US Environmental Protection Agency (EPA), the US Geological Survey, the American Society for Testing and Materials (ASTM), or the American Public Health Association were considered suitable for interlaboratory comparison.

Two general chemical classes, metals and polychlorinated biphenyls (PCBs), were chosen for this study. These classes represent two diverse methodologies and are characteristic of a major portion of the analytical effort expended by the Corps' division laboratories.

The US Army Engineer Waterways Experiment Station's Analytical Laboratory Group (ALG) is coordinating this testing program. In early August 1987 all of the division laboratories were contacted about the pilot study and notified of sample shipment. Information was provided regarding sample matrix and identification, requested analyses, suggested methodologies, and required detection limits. Additional instructions were provided with the samples, requesting that a duplicate and spike analysis be performed for each parameter. Shortly after the samples were shipped, two of the division laboratories indicated that they would be unable to perform the analyses

Analyzing metals by plasma emission spectroscopy



due to personnel losses, thus reducing the number of participants to six. Table 1 contains basic information provided prior to shipment.

The ALG prepared samples by spiking deionized distilled water with quality-control check solutions obtained from the EPA. Target ranges for acceptable data were established based on the actual concentrations as reported by the EPA and data that their referee laboratories had obtained for these solutions. Upon initial receipt of the pilot study test results, laboratories with data falling outside these target ranges were notified by telephone and told which parameters needed to be checked. Since this was a pilot study, the revised data were used to prepare the statistical analysis.

Test Results

The results were statistically evaluated using techniques described in "Statistical Manual of the Association of Official Analytical Chemists" (1975) by W. J. Youden and E. H. Steiner. Tables 2 and 3 summarize the results obtained for the two samples. Tables 4 and 5 summarize the internal spike recoveries at the laboratories.

Table 1. Sample Information Provided to Division Laboratories

Sample Identity	*Containers and Preservative*	*Requested Analyses and Suggested Methods (EPA)*	*Required Detection Limits*
Wat-Metals-1	Two 500-ml plastic bottles, HNO_3	As-6010, 206.2 or 206.3	50 μg/ℓ
		Ba-6010, 208.2	50 μg/ℓ
		Cd-6010, 213.2	10 μg/ℓ
		Cr-6010, 218.2	50 μg/ℓ
		Pb-6010, 239.2	50 μg/ℓ
		Hg-245.1, 245.2	0.2 μg/ℓ
		Ag-6010, 272.2	50 μg/ℓ
		Se-6010, 270.2 or 270.3	10 μg/ℓ
Wat-PCB-1	Three 1-ℓ glass bottles Cool, 4° C	PCB Aroclors-608	0.5 μg/ℓ

Note: Chemical symbols are as follows: arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), lead (Pb), mercury (Hg), silver (Ag), and selenium (Se).

Table 2. Metals in Water Check Sample Summary of Results, Average Values (mg/ℓ)

Lab Code	*As*	*Ba*	*Cd*	*Cr*	*Pb*	*Hg*	*Se*	*Ag*
1	0.226	4.84	0.0485	0.276	0.270	0.0102	0.046	0.205
2	0.225	4.25	0.0490	0.255	0.282	0.0107	0.052	0.270
3	0.235	5.06	0.0545	0.266	0.320	0.0056	0.055	0.287
4	0.320	5.05	0.0745	0.260	0.240	0.0105	0.054	0.310
5	0.250	4.95	0.0500	0.275	0.275	0.0094	0.059	0.250
6	0.190	4.89	0.0480	0.242	0.237	0.0130	0.049	0.250
Mean	0.241	4.84	0.0540	0.262	0.271	0.0099	0.050	0.262
Standard deviation	0.043	0.30	0.010	0.025	0.031	0.0024	0.005	0.036
Amount added	0.250	5.00	0.050	0.250	0.250	0.0100	0.050	0.250
Percent bias	-3.6	-3.2	+8.0	+4.8	+8.4	-1.0	0.	+4.8

Table 3. PCBs in Water Check Sample, Summary of Results, Average Values (μg/ℓ)

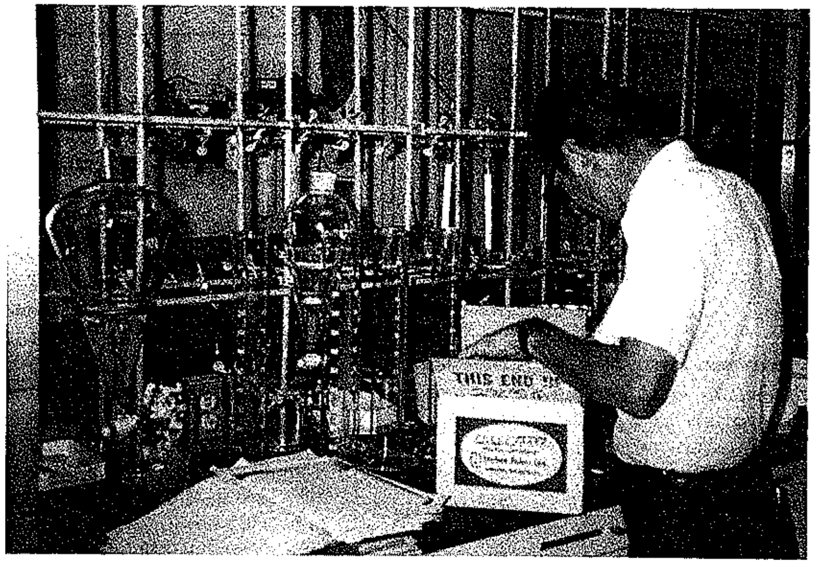
Laboratory Code	*Aroclor-1248*
1	4.4
2	8.6
3	7.8
4	9.4
5	9.8
6	10.0
Mean	8.3
Standard deviation	2.0
Amount added	10.0

Note: All labs identified Aroclor correctly.

Table 4. Metals Check Sample, Summary of Internal Spike Recoveries, percent

Lab Code	*As*	*Ba*	*Cd*	*Cr*	*Pb*	*Hg*	*Se*	*Ag*
1	81	96	92	94	90	105	91	89
2	91	114	88	106	92	93	102	101
3	98	NR	NR	NR	NR	100	97	NR
4	97	95	99	98	100	93	104	97
5	106	80	99	111	106	105	84	55
6	90	101	100	99	114	95	112	96

Note: NR indicates not reported.



Preparing audit samples for shipping

Table 5. PCB Check Sample, Summary of Internal Spike Recoveries, percent

Lab Code	*PCB Spike Recovery*
1	64
2	95
3	113
4	95
5	113
6	80

Conclusions

The standard deviations obtained for the metals analyses compared favorably with data previously reported by EPA and by commercial vendors for their audit samples. Differences in duplicate values reported by the laboratories were small, thus attributing the largest portion of the systematic error to individual laboratory biases. The range of values for the PCB analysis appears large, but it is within the acceptable limits (4-16 micrograms/litre) of the method as determined by EPA. Overall, the data for the division laboratories were very good, indicating that analyses performed by them for metals and PCBs in water are reliable and that instrumentation and calibrating materials are sufficient to provide accurate and precise data.

The Corps' Interlaboratory Testing Program is scheduled to begin operation in 1988. The majority of parameters normally analyzed by the division laboratories will be covered in this program. In addition to water matrices, future studies are planned to include real-world sediment samples for analysis. These will provide information on a laboratory's ability to perform sample digestions and extractions and to assess interferences and complex spectra.

In the first article, reaeration at low-head gated structures is discussed. Reaeration at hydraulic structures can be a major source of water-quality maintenance or improvement on our Nation's inland waters. The second article discusses a pilot study to evaluate the Corps' Interlaboratory Testing Program for chemical analysis. Precise chemical analysis is necessary so that data furnished by Corps laboratories can be used to fulfill regulatory requirements for acceptable quality assurance.

WATER QUALITY RESEARCH PROGRAM

This bulletin is published in accordance with AR 310-2. It has been prepared and distributed as one of the information dissemination functions of the Waterways Experiment Station. It is principally intended to be a forum whereby information pertaining to and resulting from WQRP can be rapidly and widely disseminated to Corps District and Division offices as well as other Federal agencies, state agencies, universities, research institutes, corporations, and individuals. Contributions of any type are solicited from all sources and will be considered for publication as long as they are relevant to the objectives of WQRP, i.e., to provide new or improved technology to solve selected environmental quality problems associated with Civil Works activities of the Corps of Engineers in a manner compatible with authorized project purposes. This bulletin will be issued on an irregular basis as dictated by the quantity and importance of information to be disseminated. Communications are welcomed and should be addressed to the Environmental Laboratory, ATTN: J.L. Decell, U.S. Army Engineer Waterways Experiment Station, P.O. Box 631, Vicksburg, Mississippi 39180-0631, or call AC 601/634-3494.

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