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DISPERSION CHARACTERISTICS
OF THE COLUMBIA RIVER
BETWEEN RIVER MILES 383 AND 355

October 1970

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ERRATA

The equation in the second sentence of the second paragraph on page 3 and the equation displayed on page 24 should read:

$$D_y \propto u_* h$$

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BETWEEN RIVER MILES 383 AND 355

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ABSTRACT

This report contains an analysis of the dispersion characteristics of the Columbia River between River Miles 383 and 355. The techniques employed included both remote sensing systems and physical contact sampling systems. Both techniques used dye as a tracer. The effect of effluent buoyancy on the lateral dispersion coefficient is empirically examined. Results indicate that the lateral diffusion coefficient depends upon density differentials. Values for the longitudinal diffusion coefficient generally range between $500 \text{ ft}^2/\text{sec}$ and $3000 \text{ ft}^2/\text{sec}$ for flow rates of 80,000 to 130,000 ft^3/sec .

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INTRODUCTION

In recent years, the natural mixing of the Columbia River between River Miles 383 and 355 has attracted much attention because of this area's use by the Atomic Energy Commission. During the past 25 years, no less than five plutonium-producing and power-producing reactor complexes have been sited on these waters. In the 1950's, a study was begun to define the behavior of reactor cooling water once it was discharged into the Columbia River. The long-term objective of the study was to develop capabilities to assist in predicting the response and ultimate fate of reactor effluent (temperature and radioactivity) once introduced into flowing streams.

The general problem under consideration is basically that of determining how two heterogeneous fluids mix in a free, turbulent flow. To date, attention has primarily been focused on the dispersion of seemingly neutrally buoyant substances in flowing fields for which a totally analytical approach is presently inadequate. Heterogeneity of the fluids further complicates an already seemingly insoluble problem.

Using measurements taken in situ, Honstead⁽¹⁾ concluded that prompt mixing existed in the vertical plane and homogeneity also existed in the vertical plane at distances from 200 to 300 yd below the release point. Because the tracer employed by Honstead was a thermally active, buoyant effluent, it was concluded that, conservatively speaking, any neutral buoyant substance would demonstrate these same characteristics. In addition, Jaske⁽²⁾ conjectured from visual

observation that within this same zone, the turbulent momentum fluctuations associated with the effluent momentum were also dissipated. Since that time, cursory measurements have verified that conjecture.

Based upon these two findings and realizing the numerous deficiencies in our basic understanding of free turbulent mixing, Jaske developed the COLHEAT simulation system. This system, based primarily upon a mass and thermal energy balance, divides the river reach under examination into discrete sections utilizing time averaged representations. To date no rigorous treatment of the momentum relationships has been included. The system conceived was first documented in 1966⁽³⁾ and since that time has received much attention and has undergone much development. Since its inception, the COLHEAT simulation system on numerous occasions has demonstrated its versatility and capability in simulating the temperature distribution of streams (for example, see References 4, 5, 6, and 7. However, we must note that much work remains to be done in order to quantitatively relate the dispersive capacity of the river to the basic physical characteristics of this reach.

The purpose of this report is to determine the lateral and longitudinal eddy diffusion coefficients for the section of river between River Miles 383 and 355 and, where possible, to relate these coefficients to the basic hydraulic characteristics of the reach.

SUMMARY AND CONCLUSIONS

The section of river under examination was divided into three reaches. Beginning with the reach farthest upstream, the reaches extended in sequence from River Mile 383 to 376, Mile 376 to 370, and Mile 370 to 355. The range of values for the longitudinal dispersion coefficient varied from 600 ft²/sec to 5000 ft²/sec for the reaches and flow rates examined. The measured coefficients of the upper and lower reaches appear

consistent. The dispersion coefficient increases with increasing flow rate. However, the measured coefficients of the central reach appear to behave more randomly. In comparison, the values range from 10 to 100 times greater than predicted quantities using Elder's model.⁽⁸⁾ Using Fisher's model,⁽⁹⁾ the predicted values range from 10 to 100 times greater than the measured values. However, we should note that the analysis and subsequent results shown here are based upon data collected during the convective period as defined by Fisher. Since the basic shape of the dispersion curve obtained from field measurements did not show a distinct skew, no attempt was made to compute the longitudinal dispersion coefficient using Hays'⁽¹⁰⁾ dead zone model.

Only the lateral dispersion of the upper reach was examined. Under nonheated conditions, the lateral diffusion coefficient of the plume was found to equal $2 \text{ ft}^2/\text{sec}$, which compares very well with results published previously by Glover⁽¹¹⁾ for the same section of river. This finding suggests that the diffusion approximation in the lateral direction ($D_y = 0.23U_*h$) can be employed for nonheated conditions from the point at which the effect of the effluent discharge momentum ceases to exist. This does not suggest uniform or constant lateral dispersion downstream. The tests that were run using a heated condition indicate that the effective diffusion coefficient is larger than the effective or apparent diffusion coefficient under nonheated conditions. Assuming the dye solution to be hydrodynamically indistinguishable from normally heated effluent, the thermal eddy diffusivity of the heat plume is therefore larger than the mass eddy diffusivity. This results from the heterogeneous nature of the gradient temperature distribution in the lateral direction and should continue until the gradient is no longer hydrodynamically significant. At this time, the dispersion should be governed by the natural mixing of the river.

LONGITUDINAL DISPERSION

Taylor⁽¹²⁾ was the first to suggest the use of the convective diffusion differential equation for modeling the dispersion of a substance in fluid fields. He hypothesized that the dispersal mechanism might be viewed as a diffusion process. Confining his investigation to dispersion of a neutral buoyant substance in pipe flow, he verified this hypothesis. Elder⁽⁸⁾ extended the approach suggested by Taylor to the case of turbulent flow in a wide channel with a free surface. Elder's research concluded that the diffusion coefficient was proportional to the product of the local depth and shear velocity. Since 1959, reasonable correlation between theoretical and laboratory results have occurred on a number of occasions. The most notable of these correlations resulted from the work performed by Glover.⁽¹¹⁾

Although reasonable correlation has been obtained in the laboratory, results obtained using field measurements have not been so rewarding. The dispersion characteristics in natural streams as measured by the diffusion coefficient have been observed to vary substantially from stream to stream. As a result, a number of researchers in attempting to model the behavior of suspended materials in streams have at times questioned the validity of Taylor's approach. Therefore, it is essential to review three assumptions and limitations placed upon both Taylor's and Elder's analyses: (1) both studies employed steady-state flow, (2) both studies were performed imposing a uniform cross-sectional geometry, and (3) both studies assumed a homogeneous receiving body of spacial uniformity.

Rarely do all three of these conditions prevail in field studies. However, Fisher has shown that Taylor's approach can be employed if properly applied, providing extensive dead zones do not exist in the reach as discussed by Hays.⁽¹⁰⁾ As a result, determination of the general dispersive nature of streams still

relies heavily upon experimental data obtained from in situ measurements. The importance of this aspect can be more appreciated if one thinks in terms of our deficiency or our present inability to describe free surface turbulent flow.

DESCRIPTION OF THE REACH

The reach in question is bounded by Coyote Rapids at River Mile 383 on the upstream end and River Mile 355 on the downstream end. Within this reach, the river was further subdivided into three sections or reaches (see Figure 1).

The section farthest upstream extends from River Mile 383 to River Mile 376. This section of the river is essentially straight, possessing a uniform cross section and approximately a constant width. The second or middle section extends from River Mile 376 to the vacated White Bluffs Ferry Landing. Between these two stations, the river makes a 90° bend and contains a number of large islands. The third or downstream section of the reach extends from the White Bluffs Ferry Landing at the upstream end to River Mile 355 on the downstream end. This section is best characterized as generally a mean between the extremes previously discussed. The reach first turns slightly to the west and then to the east. In addition, it contains a number of small islands.

The following discussion will examine the longitudinal mixing within each of these three sections.

FIELD MEASUREMENTS

A number of dye releases have taken place on the reach of Columbia River under examination. Both instantaneous and continuous releases have been made. In this study, we will confine our analysis to a set of instantaneous releases.

In all cases, dye was released in the reactor effluent line which is analogous to a delta function or an instantaneous

FIGURE 1. Vicinity Map Showing the Three Reaches Under Consideration

release. Dye samples were then collected in the river using a G. K. Turner Model III fluorometer. The fluorometer was equipped with a continuous flow door and a Jacuzzi submersible pump. Samples were collected at several locations downstream from the release point. The technique employed was to arrive at a given location in advance of the dye and begin lateral traverses. The process would continue until the entire dye cloud passed. At this time, the sample boat and crew would travel downstream to the next sampling location and repeat the process. Thus, the sample boat and crew played "leapfrog" with the dye cloud. In all cases, rhodamine dye was used as the tracer.

Table 1 summarizes the cases examined. Table 1 provides origin of release, date of release, the average river discharge, and the locations at which samples were collected. Figure 2 illustrates each location at which the various measurements were collected.

METHODOLOGY-EVALUATION OF THE DISPERSION COEFFICIENT

The one-dimensional dispersion model, as originally formulated by Taylor, states that a dispersing cloud of tracer may be described as follows:

$$\frac{\partial \bar{C}}{\partial t} = - \bar{u} \frac{\partial \bar{C}}{\partial x} + D_x \frac{\partial^2 \bar{C}}{\partial x^2} \quad (1)$$

where

$\bar{C}$ = the cross-sectional mean concentration

$\bar{u}$ = the mean flow velocity

t = time

x = distance in the direction of mean flow.

Equation (1) states that the cloud is convected or transported downstream at the mean flow velocity while

TABLE 1. Summary of Cases Examined for Determination of Longitudinal Dispersion

Case	Origin of Release		Date of Release	Average River Discharge kft ³ /sec	Station 1		Station 2		Station 3	
	Building	River Mile			River Mile	Δx , Mile	River Mile	Δx , Mile	River Mile	Δx , Mile,
1	1908-N	379.7	9-9-64	85	376.3	3.4	369.2	10.5	354.5	25.2
2	1908-N	379.7	2-28-65	82	376.3	3.4	369.2	10.5		
3	1904-B	383.4	4-8-65	87	380.6	2.8	376.3	7.1	369.2	14.2
4	1904-B	383.4	4-4-65	53	380.6	2.8	376.3	7.1	369.2	14.2
5	1904-D	377.3	9-16-65	78	376.3	1.0	369.2	8.1		
6	1904-D	377.3	3-6-65	83	376.3	1.0	369.2	8.1	354.5	22.8
7	1904-C	383.4	8-6-64	130	380.3	3.1	378.0	5.4	369.2	14.2

FIGURE 2. Schematic Map Showing the Locations of Release and Sampling Points

dispersing or spreading out according to the classical equation for molecular diffusion. A solution to Equation (1) is as follows:

$$C(x) = \frac{C_o}{\sigma_x (2\pi)^{1/2}} e^{-x^2/2\sigma_x^2} \quad (2)$$

where

$$\sigma_x = (2D_x t)^{1/2} \quad (3)$$

Solving Equation (1) with boundary conditions corresponding to a release at the origin of time and space coordinates, the solution is:

$$\bar{C}(xt) = \frac{K_x}{t^{1/2}} e^{-\left(\frac{(x-\bar{u}t)^2}{4D_x t}\right)} \quad (4)$$

where K is a scaling factor proportional to the original concentration.

The data collected in the field was reduced to a form compatible for analysis through the use of Equation (4). Thus, for a given location the average concentration in a cross section was obtained as a function of time. This was obtained by using a weighted average of the measurements as follows:

$$\bar{C}(xt) = \frac{\sum_{i=1}^{i=n} \bar{C}_i d_i}{\sum_{i=1}^{i=n} d_i} \quad (5)$$

Stating the procedure:

The width was first divided into n equal lengths; thus the product of the average local concentration ($\bar{C}_i$) and local depth (d_i) was summed over a complete traverse. The product in turn

was divided by the summation of the local depths. Using this approach rendered the data in a form shown in Figure 3. Note the procedure takes advantage of Honstead's finding of homogeneity in the vertical plane. The next step was to evaluate the variables K_x , D_x , $\bar{u}$ as a function of the measured variables $\bar{c}$, x , t .

Estimates of the three variables K_x , D_x , $\bar{u}$ were obtained using nonlinear least squares. The program used was the LEARN-LIKELY algorithm developed by the Physics and Engineering Division of Battelle-Northwest. A complete description of the fitting algorithm has been provided in References (13) and (14).

The program called LEARN/DSPERS (see Appendix) employs the general formula

$$C = \frac{A_7}{\sqrt{td}} e^{-\frac{1}{4t} \left[\frac{(X-A_1t)^2}{A_2} + \frac{(Y-A_3t)^2}{A_4} + \frac{(Z-A_5t)^2}{A_6} \right]} \quad (6)$$

where C = concentration at tracer
 X, Y, Z = space coordinates
 A_1, A_3, A_5 = convective speed parameters
 A_2, A_4, A_6 = dispersion coefficients
 A_7 = amplitude parameter
 d = number of space dimensions
 if $d = 1$, Y and Z terms are omitted
 if $d = 2$, Z term is omitted.
 t = time elapsed

The program developed is capable of separately fitting a set of data (group of data collected at one location) or sequentially fitting several sets of data.

In addition to an estimate of the best fit provided by the LEARN/DSPERS algorithm, a CAL COMP plotting routine

FIGURE 3. Plot of Mean Concentration Versus Time-
Reduced Data for Analysis on Longitudinal
Dispersion Case Number 5 Example

was used to graphically represent the results. This overall approach is similar to a scheme suggested by Thackston and Krenkel.⁽¹⁵⁾ As mentioned above, the primary difference between the two approaches is the LEARN/DSPERS capability of sequentially fitting sets of data.

As indicated in Table 1, a total of seven cases employing the approach discussed in the preceeding paragraphs were examined in this study. An example of fitting the sets of data separately has been shown in Figures 4a and 4b using Case 5 as an example. Figure 4a fits the first set separately and Figure 4b fits the second set separately. Figure 5 has been included to illustrate the capability of simultaneously fitting sets of data. Four sets of data have been fitted in Figure 5. The data was collected at River Miles 354, 350, 345, and 341. The data was fitted using a mean velocity of 3.12 ft/sec, and a diffusion coefficient of 1564 ft²/sec. This report will include no further discussion of this data since it was collected in a section of the river downstream from the reach under consideration.

INTERPRETATION OF RESULTS

At the present time, two theories exist for evaluating the longitudinal dispersion coefficient in open channel flow providing substantial dead zone areas do not exist.

Assuming an infinitely wide and shallow channel, Elder⁽⁸⁾ employing a logarithmic velocity distribution, derived the longitudinal dispersion coefficient equal to:

$$D_1 = 5.86 hu_* \quad (7)$$

FIGURE 4a. Least Squares Fit of Data Collected
at River Mile 376.3

Neg 703538-13

FIGURE 4b. Least Squares Fit of Data Collected
at River Mile 369.2

FIGURE 5. Simultaneous Fit of 4 Sets of Data

where

$$\begin{aligned} h &= \text{depth of flow in the two dimensional channel,} \\ u_* &= \text{the shear velocity or} \\ u_* &= (gSe)^{1/2} \end{aligned} \quad (8)$$

where

$$\begin{aligned} g &= \text{the acceleration due to gravity} \\ Se &= \text{slope of the energy gradient.} \end{aligned}$$

Good agreement has been obtained on numerous occasions when Equation (7) has been used under laboratory conditions.

However, it has been shown in the field that Equation (7) consistently underestimates the measured values.

Recently, Fisher⁽⁹⁾ has assumed that the longitudinal dispersion coefficient is primarily dependent upon the lateral spreading or lateral dispersion coefficient. As a result, Fisher has placed strong emphasis on this characteristic or property in the development of his theory. The expression suggested by Fisher for the longitudinal dispersion coefficient is:

$$D_x = - \frac{1}{A} \int_0^b q'(z) dz \int_0^z \frac{1}{E_z} d(z) dz \int_0^z q'(z) dz \quad (9)$$

where

$d(z)$ = depth of flow at any point on the cross section

E_z = transverse turbulent mixing coefficient

A = area of flow cross section

b = width of channel

Y = vertical coordinate

z = transverse direction, and

q' is a flow factor based upon the actual velocity distribution. Applying Fisher's technique to the reach of the Columbia River

under examination predicts longitudinal dispersion coefficients far in excess of the measured values using a least squares fit of Taylor's model.⁽¹⁰⁾

As shown in Table 2, the dispersion coefficient increases as we move downstream from the point of release. Based upon Sayre's⁽¹⁶⁾ analysis (mixing length = 100 times average depth) it is assumed that the diffusion model can be applied at distances greater than 1/2 mile from the point of release. Therefore, the basic relationship which describes the rate of change of the variance of the tracer cloud is:

$$D_x = \frac{1}{2} \frac{d}{dt} \sigma_x^2 \quad (10)$$

Equation (10) can be derived from the diffusion equation. It is important to note Fisher⁽⁹⁾ has shown how Equation (10) can be derived without regard to the initial distribution of contaminants. In addition, if we assume that the dispersion coefficient does not change drastically with time while measurements are being collected at a specific sampling location, then samples collected at two different stations can be related through the convolution of two Gaussians, namely

$$\sigma_2^2 = \sigma_1^2 + 2(t_2 - t_1)D_{\text{interval}}$$

or

$$D_I = \frac{\sigma_2^2 - \sigma_1^2}{2(t_2 - t_1)} = \frac{t_2 D_2 - t_1 D_1}{t_2 - t_1} \quad (11)$$

Notice that the technique employed suggests the use of Munk's⁽¹⁷⁾ change of space variance with distance rather than Fisher's change of time variance with distance approach.

Equation (11) was used to establish the longitudinal dispersion coefficients over the three reaches of interest for the various flow rates. Table 3 summarizes these results.

TABLE 2. Summary of Fitted Variables at Sampling Locations

Case	Station 1				Station 2				Station 3			
	K_x $\times 10^3$	D_x ft ² /sec	$\bar{u}$ ft/sec	$\bar{t}$ min	K_x	D_x ft ² /sec	$\bar{u}$ ft/sec	$\bar{t}$ min	K_x	D_x ft ² /sec	$\bar{u}$ ft/sec	$\bar{t}$ min
1	1.41	640	3.38	88	1.14	720	4.46	207	0.761	1472	4.51	491
2	2.51	1178	3.05	98	1.70	3428	3.84	240				
3	2.03	1098	5.42	45	1.92	2038	4.1	152	1.45	3100	4.45	280
4	5.25	472	3.55	69	2.63	588	3.20	195	4.94	732	3.17	394
5	1.64	559	2.07	42	1.09	4300	3.74	190				
6	3.41	416	2.70	32	3.74	70	4.19	170	1.64	1095	4.31	465
7	1.48	484	6.70	40	1.77	600	6.02	79	0.573	1045	5.2	240

TABLE 3. Summary of the Calculated Longitudinal Dispersion Coefficient for the Three Reaches Examined

Case	Station 1		Station 2		$D_1 t_1$	$D_2 t_2$	$\Delta D_x t$	Δt	D_x	Reach	Flow
	D_x	t	D_x	t							
1	640	5,280	720	12,420	3,379,200	8,942,400	5,563,200	7,140	779	376-369	85
	720	12,420	1,472	29,460	8,942,400	43,365,120	34,422,720	17,040	2,020	369-354	
2	1,178	5,880	3,428	14,400	6,926,640	49,363,200	42,436,560	8,520	4,981	376-369	82
3	1,098	2,700	2,038	9,120	2,964,600	18,586,560	15,621,960	6,420	2,433	380-376	87
	2,038	9,120	3,100	16,800	18,586,560	52,080,000	33,493,440	7,680	4,361	376-369	
4	472	4,140	588	11,700	1,954,080	6,879,600	4,925,520	7,560	651	380-376	53
	588	11,700	732	23,640	6,879,600	17,304,480	10,424,880	11,940	873	376-369	
5	559	2,820	4,300	11,400	1,408,680	49,020,000	47,611,320	8,880	5,362	376-369	78
6	416	1,920	700	10,200	798,720	7,140,000	6,349,560	8,280	767	376-369	83
	700	10,200	1,095	27,900	7,140,000	30,550,500	23,410,500	17,700	1,323	369-354	
7	484	2,400	950	4,740	1,161,600	4,503,000	3,341,400	2,340	1,428	380-378	130
	950	4,740	1,045	14,400	4,503,000	15,048,000	10,545,000	9,660	1,092	378-369	

Two cases were examined for Reach 1, five cases were examined for Reach 2, and two cases were examined for Reach 3.

The dispersion coefficients for Reach 1 are $651 \text{ ft}^2/\text{sec}$ at a flow of $50 \text{ kft}^3/\text{sec}$ and $2433 \text{ ft}^2/\text{sec}$ at a flow of $88 \text{ kft}^3/\text{sec}$. Comparing these measured longitudinal diffusion coefficients with the existing theories indicates that: Elder's⁽⁸⁾ model underestimates the measured values by an order of magnitude, whereas Fisher's model overestimates the measured values by approximately two orders of magnitude.

As shown in Table 3, the dispersion coefficients in Reach 2 appear to behave very randomly. We feel that this results from the very abrupt change of the orientation of the momentum as the water mass turns and also results from the effect of the numerous large islands on the principal flow paths. Fisher⁽¹⁸⁾ has recently developed a dispersion model which accounts for the variation of the orientation of the momentum forces. However, it is impossible to draw any conclusions on the applicability of Fisher's Model for the reach under consideration due to the random behavior of the longitudinal dispersion coefficient for the various flow rates.

Only two cases were examined in Reach 3. Both cases were examined at approximately $85 \text{ kft}^3/\text{sec}$ and revealed somewhat consistent results. The dispersion of the river between River Miles 370 and 355 for the two cases examined was $1323 \text{ ft}^2/\text{sec}$ and $2020 \text{ ft}^2/\text{sec}$. We should note that these results compare favorably with the numerical findings covered in the Reach 1 discussion.

LATERAL DISPERSION

We know of no general theory presently existing which describes the rate of mixing transverse to the direction of flow in rivers and streams. To date, analysis has mainly relied upon the results obtained experimentally by Elder.⁽⁸⁾ For an infinitely wide channel, Elder has shown the lateral

mixing process proportional to the local depth and shear velocity. The lateral mixing is of course dependent upon the distribution of the transverse velocity field. Channel irregularities and bends introduce perturbations which can drastically distort the flow field. Except for the work recently performed by Fisher⁽⁹⁾ little attention has been directed towards integrating these aspects into the general model development. In addition, as in longitudinal mixing, no work has been performed to determine the effect of density variation on the mixing of substances in free surface fluid flow. In this study, the effect of density variation on the initial transverse dispersion will be examined. Using the existing facilities at 100KE, the empirical analysis will be confined to examination of the response just downstream from the release point.

In 1954, a study was performed by Honstead⁽¹⁾ in which a mixture of short-lived radioactive isotopes was released from the B Reactor (River Mile 383) into the Columbia River and traced downstream.

A total of ten sampling locations were selected at distances of 950, 1,750, 2,850, 3,590, 6,230, 8,870, 14,150, 14,430, 24,710, and 29,990 ft from the point of discharge. Samples were collected at a uniform depth of 3 ft below the water surface on a line perpendicular to the direction of flow. The flow rate of the river was 62,000 ft³/sec.

These measurements were first analyzed by Norton.⁽¹⁹⁾ Norton's analysis indicated that the rate of spread varied significantly from one sample location to another. Using this same data, Glover⁽¹⁰⁾ determined the diffusion coefficient (D_y) to equal 2.1 ft²/sec. However, the analysis was confined to the three sets of measurements collected 2850 to 6230 ft from the actual release point. Jaske⁽²⁾ recently using temperature as a tracer, extended the analysis to describe

the behavior of the lateral mixing of the effluent in the Columbia River to within 400 yd of the release point.

As mentioned previously, the purpose of this study was to examine the behavior of the effluent within the first few hundred yards of release. Until recently, this was not considered feasible because existing physical sampling techniques could not be efficiently applied on a river as large and swift as the Columbia. Now, however, development of remote sensing techniques at Battelle-Northwest has since made the proposed analysis possible.

SAMPLING TECHNIQUE

As previously mentioned, dye was released into the reactor effluent line at the 100KE facility. The dye traveled from the point of release (1904 Building) to the river via the flow in the effluent line. On all occasions, the dye was mixed to a specific gravity which was equal to that of the river flow. Remote scanning techniques were used to examine the behavior of the effluent as it flowed into the river. The system and technique employed has recently been documented by the developers Eliason and Foote.⁽²⁰⁾

Briefly, the system employed is defined as a passive optical mechanical imaging unit. The system is passive in that it relies upon sunlight to excite or stimulate the fluorescence of the dye, and is mechanical in that its detection device relies upon a rotating mirror system that scans a segment of the surface normal to the flight path. The system is also optical in that the signal collects and focuses the incoming radiation on the detector. The signal is recorded on magnetic tape at a rate greater than 72,000 measurements per second.

The signal was then reconstructed in the laboratory for analysis. (See Reference 20 for a more complete discussion of the technique employed.)

CASES EXAMINED

A total of five releases were performed. Two releases were made under nonheated conditions at flow rates of 50 and 100 kft³/sec, and three heated releases were made at flow rates of 75, 110, and 145 kft³/sec. Special arrangements were made with the personnel at Douglas United Nuclear to provide normal operational flows under no load conditions for the nonheated (cold) runs. The heated runs were performed under normal operating conditions.

Fluorescent dye was employed to enable the examination of the initial behavior of the effluent in the receiving body which was the original purpose of this study. Alcohol and water was used to mix the dye to the proper density. The solution was then released in the effluent line at a rate of approximately 1/4 lb of dye/min. Figure 6 provides a schematic representation of the overall technique employed for examining the lateral dispersion.

INTERPRETATION OF RESULTS

As stated previously, no theory presently exists for predicting mixing in the lateral direction. To date, primary emphasis has been placed upon using the results obtained empirically by Elder.⁽⁸⁾

Elder has shown the lateral dispersion coefficient can be calculated as follows:

$$D_y = 0.23 u_* h$$

Five cases were examined in this study to compare the effect of buoyancy on the initial mixing. As would be expected, the data collected can be represented in a number of ways. For this study, the data collected on magnetic tape was transferred into a graphical plot form using a Clevite plotter. Figure 6 provides examples of the plots produced.

FIGURE 6. Schematic Representation of the Technique Employed to Measure the Lateral Dispersion

The signal intensity was arbitrarily divided into ten levels. Each of these levels appears as a contour of variable thickness on Figure 7. To assist in interpreting the concentration levels, a computer routine has been developed from which stereo pairs can be produced. The stereo viewer provides the researcher with a comprehensive picture of the surface concentration. Appropriate length scales are then superimposed upon the plots.

If we assume the distribution of the dye to be Gaussian and the dispersion process described by a diffusion process, the width of the plume at any distance (x) from the point of release can be described as follows:

$$\sigma(x) = \sigma_o + \sigma_{mix}$$

where

$\sigma(x)$ = space variance at some distance from the release point

σ_o = space variance due to the initial convective mixing

σ_{mix} = dispersion represented by the process of diffusion beginning at the end of the convective mixing period.

Therefore

$$\sigma_{mix} = (2D_y t)^{1/2}$$

where

D_y = lateral diffusion coefficient (ft^2/sec).

Once again employing the theory of convolution, the diffusion coefficient can be determined as follows:

$$D_y = \frac{\sigma_2^2 - \sigma_1^2}{2(\Delta t)}$$

where σ_1 is a space variance.

FIGURE 7. An Example of Technique Employed for Reduction of Data
Pertaining to the Examination of Lateral Dispersion

Assuming that we can scale 4σ or 95% of the tracer in the lateral direction, any two measured widths can then be related:

$$D_y = \frac{W_2^2 - W_1^2}{32\Delta t}$$

or assuming a uniform conveyance velocity

$$D_y = \frac{W_2^2 - W_1^2}{32\left(\frac{\Delta x}{\bar{u}}\right)}$$

Recalling the statements made previously on the dissipation of effluent momentum, the lateral diffusion coefficient can then be determined as follows:

$$D_y = \frac{W_{(x)}^2 - W_o^2}{32\left(\frac{X - X_o}{\bar{u}}\right)}$$

where

$W_{(x)}$ = width at some distance X from X_o

W_o = initial width at tracer

X_o = origin of the diffusion process.

All five cases were reduced using this approach. These have been tabulated in Table 4.

Both cases run under neutral buoyant conditions reveal a lateral diffusion coefficient approximately equal to $2 \text{ ft}^2/\text{sec}$. These results agree with the work previously performed by Glover.⁽¹⁰⁾ Under heated conditions, the lateral diffusion coefficient was generally higher. If we assume the dye particles to be of zero size, and since the concentration of the dye is less than 10 ppb, the mixture of fluid and dye should have essentially the same density and kinematic viscosity as normally heated effluent. Therefore, we can state that the solute is hydrodynamically indistinguishable from the

TABLE 4. A Comparison of the Average Lateral Diffusion Coefficient for the Heated and Nonheated Cases

$x, \text{ ft}$	$x_o, \text{ ft}$	$w_o, \text{ ft}$	$w_x, \text{ ft}$	$\bar{u}$ ft/sec	$\bar{D}_y^2$ ft ² /sec
Q = 80 kft ³ /sec, reactor up					
	100	29		3.3	
300	100	29	86	3.3	3.38
500	100	29	144	3.3	5.10
700	100	29	202	3.3	6.84
900	100	29	202	3.3	5.10
1100	100	29	260	3.3	6.90
1300	100	29	260	3.3	6.22
1500	100	29	230	3.3	3.82
1700	100	29	275	3.3	5.17
				$\bar{D}_y = 5.32$	
Q = 110 kft ³ /sec, reactor up					
	112	29		4.2	
200	112	29	43	4.2	1.51
400	112	29	100	4.2	4.18
600	112	29	160	4.2	6.60
800	112	29	260	4.2	12.60
1000	112	29	290	4.2	12.22
1200	112	29	200	4.2	8.30
1400	112	29	245	4.2	6.00
				$\bar{D}_y = 7.36$	
Q = 145 kft ³ /sec, reactor up					
	150	20		5.1	
200			29		1.42
400			58		1.61
600			115		4.32
800			129		3.88
1000			101		1.76
1200			172		4.58
				$\bar{D}_y = 2.93$	
Q = 50 kft ³ /sec, reactor down					
	150	20		2.0	
200			29		0.55
400			100		2.40
600			129		2.25
800			129		1.55
1000			186		2.45
1200			200		2.30
				<u>11.50</u>	
				$\bar{D}_y = 1.91$	
Q = 100 kft ³ /sec, reactor down					
	150	20		4.1	
200			41	4.1	3.32
400			54		1.29
600			80		1.71
800			100		1.90
1000			120		2.10
1200			120		<u>1.71</u>
				12.03	
				$\bar{D}_y = 2.00$	

normally heated effluent. Consequently, the eddy diffusivity coefficient of the heated plume would appear to be greater than the natural eddy diffusivity of the river for the cases examined.

It is believed that as the momentum of the receiving water increases, the difference between these two coefficients will decrease asymptotically approaching the eddy diffusivity of the river. This statement is based upon the behavior of the effective diffusivity coefficient as shown in Table 4. As the river flow increases the values of the diffusion coefficients tend to converge for both heated and non-heated cases.

APPENDIX

The LEARN/DSPERS computer program is a particular realization of the general nonlinear least-squares fitting package LEARN-I-C. It is designed to fit concentration measurements of a dispersing tracer as a function of position and time in a uniformly flowing stream following the instantaneous release of a small quantity. The assumed functional form is given as Equation (6) in the main text.

The LEARN-I-C package is an improved version of the LEARN-I-A package described in Reference 14. It is a segmented program written in FORTRAN-V and designed for use with the CSCX executive system for the UNIVAC 1108 computer. Some of the salient characteristics of the general package will be described briefly here. A quite general nonlinear function f of the adjustable parameters is permitted,

$$f = f(x_i, a_j), \quad (12)$$

where x_i are the independent variables, and a_j are the parameters to be adjusted. Using an initial guess for the parameters and information provided by the first and second partial derivatives $\partial f / \partial a_j$ and $\partial^2 f / \partial a_j \partial a_k$, as well as Equation (12), the program proceeds iteratively to minimize the weighted sum of squares of residuals. In order to obtain reliable and speedy convergence, even in the presence of severe nonlinearity and correlation, a combination of Newton's method and a gradient method is used. Saddle points are explicitly recognized and avoided. Following convergence to a minimum, parameter error estimates are calculated (assuming the residuals are "errors"), and an extensive statistical analysis is performed. Quite flexible plotting of the data and fitted curves may also be done. For details concerning the principles and operational details of the general LEARN package, see references 13 and 14.

The following paragraphs give a brief description of the noteworthy features of the LEARN/DSPERS program. One important feature is its flexible spatial dimensionality. The same program is used for one-, two-, and three-dimensional fitting. The number of spatial dimensions is an input parameter.

When the number of independent variables is two (as in the cases discussed in the text), the fitting process involves a surface rather than simply a curve. A large variety of situations concerning the data are then possible. For example, the data may be obtained at a random set of space-time points. They may be obtained simultaneously at several positions or sequentially in time at one or more positions. In the cases analyzed, the measurements were of the latter type. In this situation, one may use all the data in a single computer run to get a set of "effective" parameters for the entire experiment. Alternatively, one may use portions of the data in several runs to obtain information about selected parts of the experiment. Both types of runs have been made.

Another important feature of the program is the ability to hold the values of any subset of the parameters fixed at the input values. This is useful if a set of data cannot determine well the entire set of parameters, and if independent information on the parameters is available. For example, suppose we have a case of two-dimensional dispersion in which a small blob spreads on the surface of a stream having a uniform velocity in the x -direction. If all the measurements are made along the longitudinal axis of the blob (that is, at $y = 0$), then we cannot determine the transverse dispersion coefficient A_4 . However, by fixing $A_3 = 0$ and $A_4 =$ any finite number, we can still determine A_1 , A_2 and A_7 .

REFERENCES

1. J. F. Honstead. Dispersion of Dissolved Material in the Columbia River, HW-49008. Available from Clearinghouse for Federal Scientific and Technical Information, March 1957.
2. R. T. Jaske. Unpublished Data. Battelle-Northwest, June 1967. (Preliminary Report: An Analysis of the Physical Factors Governing the Size and Temperature Gradients of the Hanford Effluent Plumes)
3. R. T. Jaske. An Evaluation of the Use of Selective Discharges from Lake Roosevelt to Cool the Columbia River, BNWL-208. February 1966.
4. R. T. Jaske. A Test Simulation of the Temperature of the Illinois River and a Prediction of the Effects of Dresden II and Dresden III Reactors, BNWL-728. April 1968.
5. D. E. Peterson and R. T. Jaske. A Test Simulation of the Potential Effects of Thermal Power Plants on Streams in the Upper Mississippi River Basin, BNWL-999. December 1968.
6. D. E. Peterson and R. T. Jaske. Potential Thermal Effects of an Expanding Power Industry, Ohio River Basin 1, BNWL-1299. February 1970.
7. D. E. Peterson and R. T. Jaske. Potential Thermal Effects of an Expanding Power Industry Upper Mississippi River Basin, BNWL-1405. June 1970.
8. J. W. Elder. "The Dispersion of Marked Fluid in Turbulent Stream Flow," J. of Fluid Mech. vol. 5. 1959.
9. H. B. Fisher. Longitudinal Dispersion in Laboratory and Natural Streams, KH-R-12. W. M. Keck Laboratory, C.I.T., 1966.
10. J. R. Hays. Mass Transport Mechanisms in Open Channel Flow. Vanderbilt University, 1966. (Ph.D. Dissertation)
11. R. E. Glover. "Dispersion of Dissolved or Suspended Materials in Flowing Streams," U.S. Geol. Surv., Profess. Paper 433-B. 1964.
12. G. I. Taylor. "Dispersion of Soluble Matter in Solvent Flowing Slowly Through a Tube," Proc. Roy. Soc., Ser. A: 219. 1953.
13. B. H. Duane. Maximum Likelihood Nonlinear Correlated Fields, BNWL-390. September 1967.
14. G. D. Seybold. Users Aid: Programs LEARN and LIKELY, BNWL-1057. May 1969.

15. E. L. Thackston and P. A. Kuenkel. "Longitudinal Mixing Natural Stream," J. Sanit. Eng. Div., Am. Soc. Civ. Engrs., vol. 93, p. SA567. October 1967.
16. W. W. Sayre and A. R. Chamberlain. "Exploratory Laboratory Study of Lateral Turbulent Diffusion at the Surface of An Alluvial Channel," U.S. Geol. Surv. Circ. 484. 1964.
17. W. H. Munk et al. "Diffusion in Bikini Lagoon," Trans. Am. Geophys. Union, vol. 30. 1949.
18. H. B. Fischer. "The Effects of Bends on Dispersion in Streams," Water Resources Research, vol. 5, no. 2. 1969.
19. H. T. Norton. The Turbulent Diffusion of River Contaminants, HW-49195. Available from Clearance for Federal Scientific and Technical Information, Springfield, Virginia.
20. J. P. Eliason and H. P. Foote. Dye Studies Through Use of Advancements in an Aerial Optical Mechanical Imaging System, BNWL-SA-3204. April 1970.

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