Northwest and Alaska Fisheries Center Processed Report*

DISPERSION OF DROGUES: AN ESTIMATION OF POLLUTANT DISPERSAL IN PORT VALDEZ, ALASKA

by

M. J. Pelto, R. W. Williamson, and J. Knull*

October 1978

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northwest and Alaska Fisheries Center
2725 Montlake Boulevard East
Seattle, Washington 98112

* This report does not constitute a publication and is for information only. All data herein are to be considered provisional.

DISPERSION OF DROGUES: A ESTIMATION OF POLLUTANT DISPERSAL IN PORT VALDEZ, ALASKA

by

M. J. Pelto, R. W. Williamson, and J. Knull*

October 1978

*Northwest and Alaska Fisheries Center Auke Bay Laboratory
National Marine Fisheries Service, NOAA
P.O. Box 155, Auke Bay, AK 99821

DISPERSION OF DROGUES: A ESTIMATION OF POLLUTANT DISPERSAL IN PORT VALDEZ, ALASKA

by

M. J. Pelto, R. W. Williamson, and J. Knull*

October 1978

*Northwest and Alaska Fisheries Center Auke Bay Laboratory
National Marine Fisheries Service, NOAA
P.O. Box 155, Auke Bay, AK 99821

CONTENTS

Figures

Table

DISPERSION OF DROGUES: AN ESTIMATION OF POLLUTANT DISPERSAL IN PORT VALDEZ, ALASKA

M. J. Pelto, R. W. Williamson, and J. Knull

INTRODUCTION

The southern terminus of the Trans-Alaska Pipeline includes a treatment plant for oil tanker ballast water. Treated ballast water is discharged into Port Valdez by a diffuser along the bottom off Jackson Point. The diffuser effluent plume may contain as much as 10 ppm of oil which will be dispersed into Port Valdez by turbulence induced by tidal currents.

Background data for any pollution control program include estimates of the dispersal rate of effluents. From the dispersal rate the areas of given concentrations of effluents are calculated. Since dispersal rates vary widely and are difficult to estimate from other data, such as winds, depth, current velocity, and bathymetry, it was felt necessary to measure the dispersal rates directly by use of drogues.

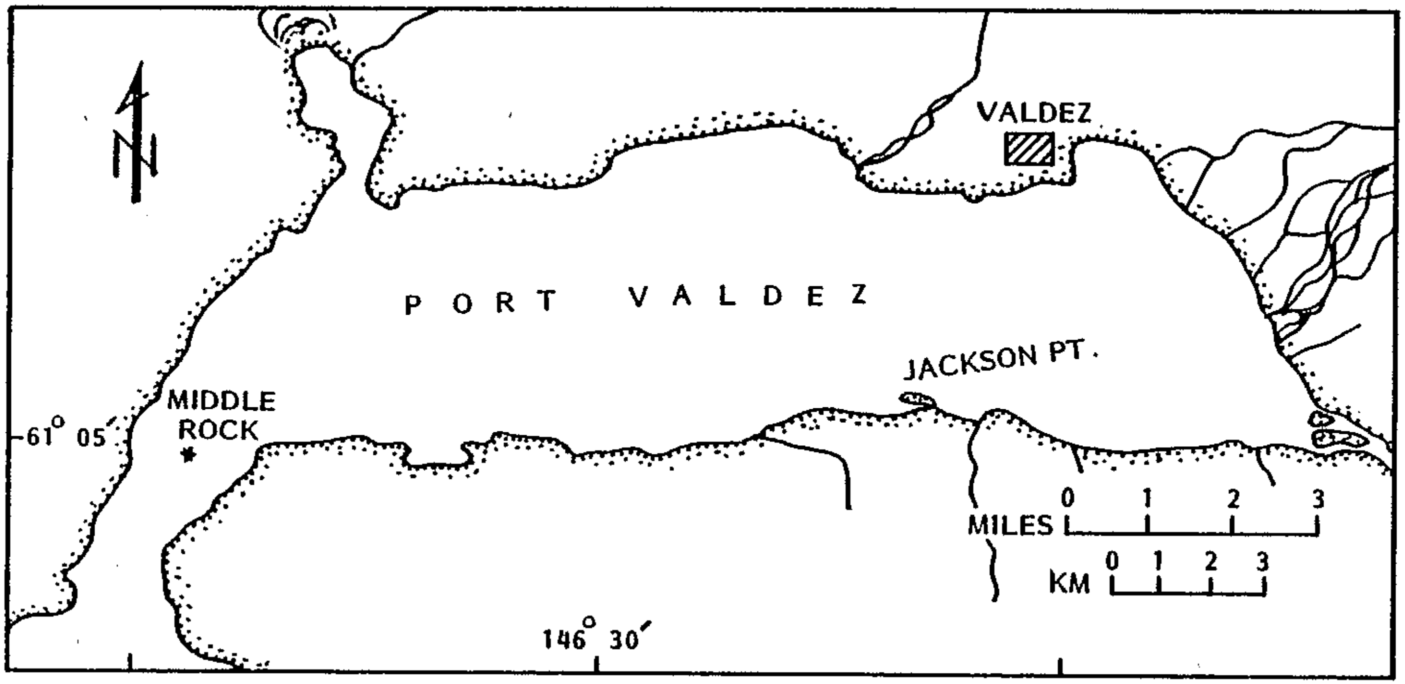
The study reported here was designed to determine the dispersal rates of oil under worst case conditions. It is assumed that dispersal rates will be least in the surface layer of water above the pycnocline under windless conditions. Under most conditions, the effluent plume from the diffuser will remain below the surface if the ballast water is of higher salinity (denser) than the water of Port Valdez. However, if ballast water originates in a low-salinity estuary and is warmer than Port Valdez, the effluent plume from the diffuser will surface or rise to a point just below the pycnocline where turbulent mixing will carry a part of the oil to the surface.

Study Area and Conditions

Port Valdez (Figure 1) is a typical, steep-sided, fiord-type estuary in Prince William Sound in southcentral Alaska. It is 20 km in length, 4 km in width, and 245 m in depth. The mouth is restricted to 1.6 km in width and has a sill depth of 180 m. The mouth is further restricted by a rock which is above the surface near mid channel.

Several small streams enter Port Valdez, the principal one being the Lowe River which enters at the head of the bay at its east end. As a result of the annual streamflow cycle, a sharp pycnocline forms in the bay during the summer. During the period of the study, the pycnocline was found between the surface and 6 m.

Figure 1.--Port Valdez in Prince William Sound, Alaska, showing the study area at Jackson Point.



Water depths at the study site are 45-80 m. Tides in Port Valdez have a range of 3.65 m (12.0 ft). At the head of the bay where the study took place, the currents are weak, with tidal components of less than 10 cm sec^{-1} (Nebert et al. 1973).

The study took place during nearly windless weather, by design. It was intended to find dispersal rates during periods of minimum turbulence from all factors. Fortunately, during the study, 29 July to 4 August 1971, nearly windless days were experienced coincidentally with a period of minimal tidal amplitude. The tidal amplitude ranged from 1.0 to 3.0 m.

METHODS AND EQUIPMENT

Dispersion of a cluster of drogues was measured directly on photographs taken from an airplane.

The experiment was designed to be performed with 20 drogues. Actual numbers used were only 18 or 19, due to breakages and other difficulties. Each drogue consisted of a 4.3-m (14-ft) long wood 2-by-4 with a concrete weight at one end and a flag staff at the other. The flag was to prevent possible collision with small boats.

Each drogue was made visible from the air by a 1.2-m (4-ft) square of plywood, 1.9 cm (3/4 in) thick, painted white, and attached by a lanyard about 0.9 m long. The drogues floated upright with approximately a foot of the drogue above water in addition to the flag.

Photographs were taken from U.S. Fish and Wildlife Service Beaver aircraft with a 45.7-cm (18-in) camera hatch. A 35-mm single lens reflex camera, hand held, was used with black and white film.

Measurement of dispersal of the drogues was facilitated by reference to the 19.8-m (65-ft) research vessel Cripple Creek used during the study. During the operations, the vessel was kept near the drogues so it would appear in all photos.

At the beginning of each experiment, the floating drogues were herded into as tight a cluster as possible. "Herding" is used advisedly. If there is no such thing as a force of diffusion, there certainly is an apparent abhorrance of togetherness, as will be attested by those who were called on to tow and push the drogues into a cluster by outboard motor power.

In all, six runs were completed. A "run" consisted of taking pictures at approximately 5-min intervals from the minimum altitude which still allowed all drogues and the vessel to be included in the picture.

Data Processing

The variance of positions of drogues from the mean position was chosen to be the indicator of dispersion. Predictably, the pattern of drogues elongated in the direction of apparent mean motion. Therefore, two measurements of variance of position were obtained; one along the longest axis of each photographed pattern and a second one at right angles to that.

If only the variance of distance from an origin is desired, distances of each drogue from an arbitrary point may be used. It is then unnecessary to keep the origin in view as the drogues are advected by mean currents.

The variance is defined by:

$$D^2 = \frac{1}{N-1} \sum_{i=1}^{N} (X_i - \overline{X})^2, \qquad [1]$$

where X_i is the distance of the i^{th} particle from the origin and $\overline{X}$ is the mean distance of all N particles from the origin.

If the distance X_i is measured from an arbitrary point X' away from the origin, [1] may be rewritten as:

$$D^2 = \frac{1}{N-1} \sum_{i=1}^{N} [(X' + X_i) - (X' + \frac{1}{N} \sum_{i=1}^{N} X_i)]^2$$

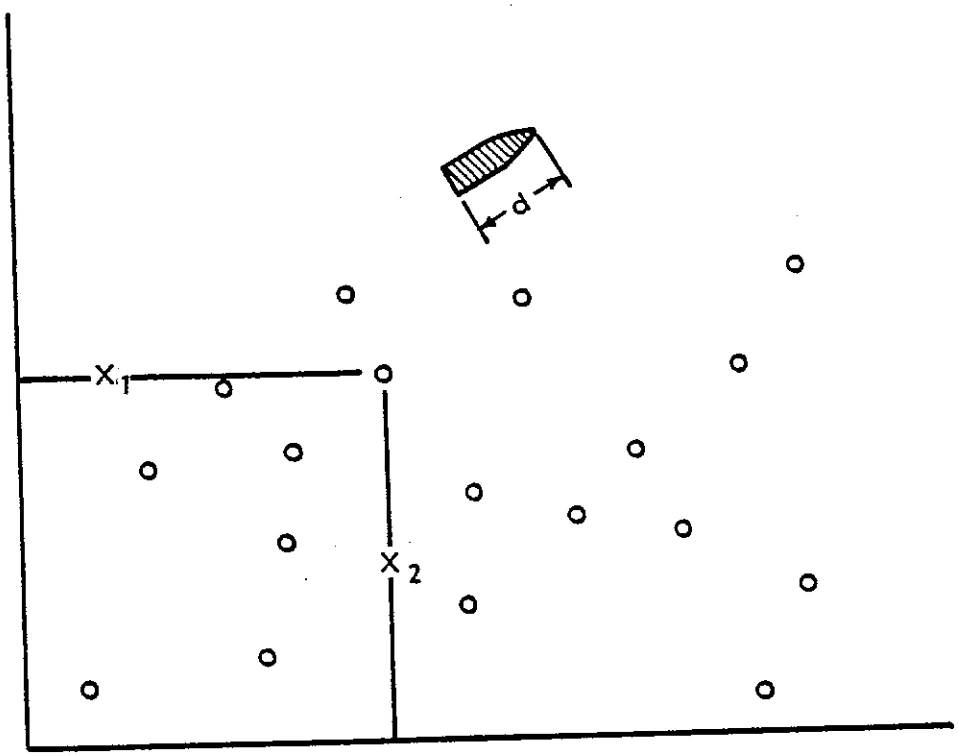
$$= \frac{1}{N-1} \sum_{i=1}^{N} (X'-X'X_i - \frac{1}{N} \sum_{i=1}^{N} X_i)^2$$

$$= \frac{1}{N-1} \sum_{i=1}^{N} (X_i - \overline{X}_i)^2. \qquad [2]$$

X_i is the incremental distance of the i^{th} particle beyond the arbitrary reference point X', and $\overline{X}$ is now the mean of all distances, X_i. Equation [2] is identical to [1] and the distance X_i may be from a different origin for each calculation without affecting D^2. The result of the above is that so long as only the variance is required, new origins may be drawn on each photo as the intersection of two axes (Figure 2).

In each photo, the distance from the axes to each drogue was measured with dividers and compared with the length of the vessel in the picture. The result was then converted to centimeters. Since the photos were taken approximately 5 min apart, it was then possible to plot the instantaneous variance in square centimeters against elapsed time, t (Figure 3a-f).

Figure 2.--Simulated drogue positions as found in photos. Axes, X_1 and X_2, are laid out; distances of drogues from these axes are determined by comparison with length of ship, d.



RESULTS

Figure 2 is a simulation of a photograph taken of the drogues, showing how distances were measured from the two axes and compared with the size of the vessel.

For each photograph, the variance of drogue position was plotted against the elapsed time after release of the drogues (Figures 3a-f).

An effective diffusivity ($K_e = 1/2(dD^2/dt)_{t \to \infty}$) may be computed from the rate of change of variance (D^2) of drogue positions, when time (t) is large (Okubo and Verber 1967). Values of K_e were found by determining the slopes in Figures 3a-f. In Port Valdez, the effective diffusivity was between 3.2×10^3 and 14.2×10^3 cm^2/sec in the longitudinal direction and in the transverse direction it was from 0.7 to 6.8 cm^2/sec (Table 1).

Dispersion across the direction of flow was always less than with the flow. The ratio between the rates of dispersion in two dimensions was highly variable, ranging from 1.0 to 22. The homogeneity of the study area is questionable, however, due to the uneven shoreline and bathymetry.

DISCUSSION

The power law curves in Figures 3a-f may each be approximated by curves of the form $D^2 = at^b$. The exponent (b) which best fits the data plotted in Figures 3a-f and tabulated in Table 1 was obtained by the method of least squares. The exponent b is highly variable and difficult to obtain with precision. The maximum value of b found was 2.5 and the minimum was 0.1.

Intuitively, values of b less than 1.0 are hard to accept as being the result of dispersion alone. If the drogues remain at a constant distance apart or if they converge, b can be shown to be 1.0 or less.

Because drogues are restrained by the water surface, a zone of down-welling will cause the drogues to converge. Dissolved or entrained oil would "down well" with the down-welling water and would continue to disperse, unlike the drogues. Therefore, it is felt that oil will disperse faster than the lowest rates at which the drogues dispersed.

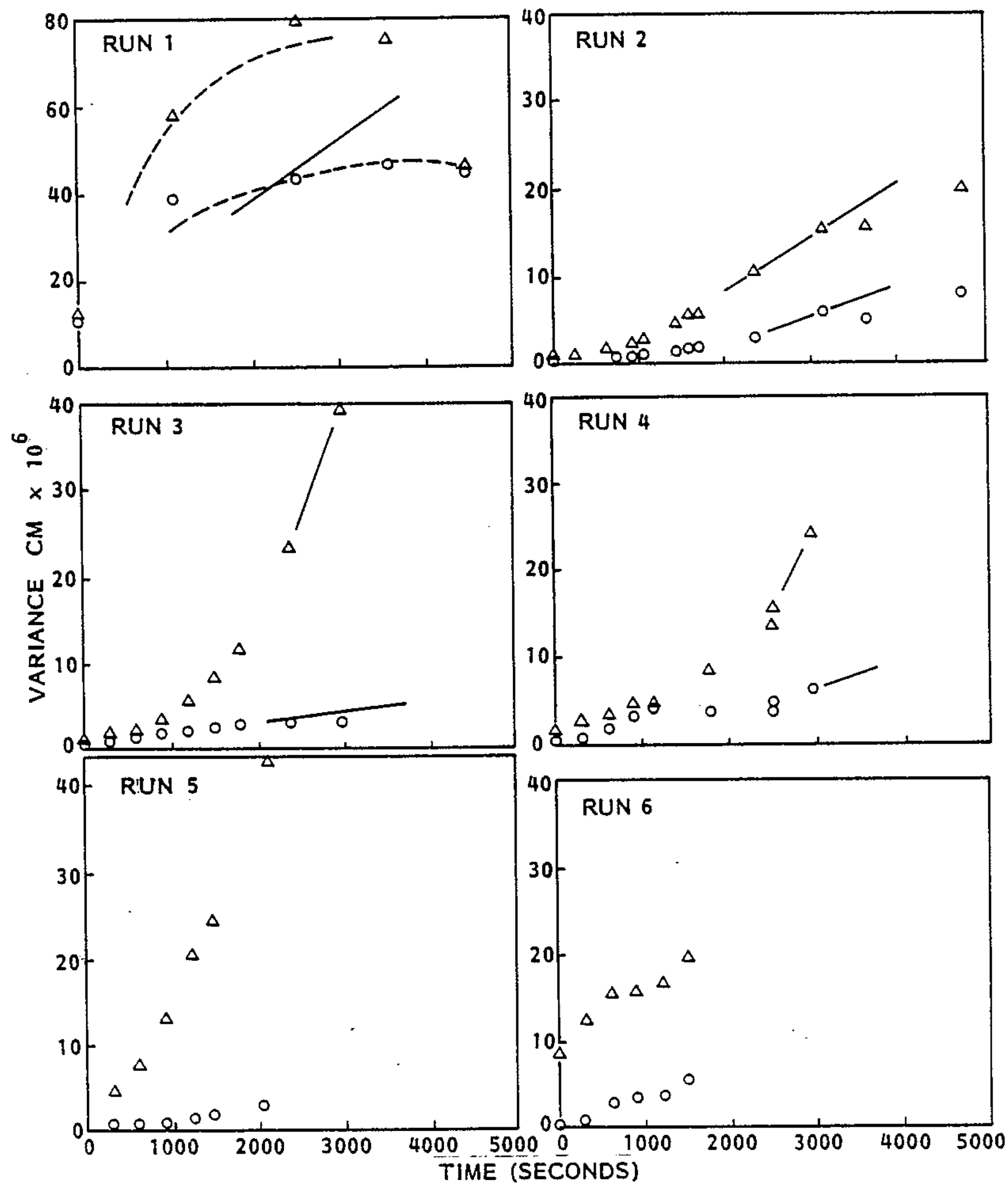
There is an indication from runs 2, 3, 4, and 5 that the variance increases according to a power law; however, there are irregularities which can be explained only by assuming that part or all of the drogues encountered a convergence in the water column. The plots for runs 4 and 6 imply that the convergences were either transient or that they and the drogues did not travel together because the curves resume the exponential character after a decrease in the rate of increase of variance.

Table 1.--Values of effective diffusivity, $K_e = 1/2\ (dD^2/dt)$, and values of b in the equation $D^2 = at^b$.

	Longitudinal		Transverse	
Run	b	K_e	b	K_e
1	(0.31)	6.8×10^3	(0.1)	6.8×10^3
2	1.39	3.2×10^3	1.71	2.0×10^3
3	2.08	13.3×10^3	(0.59)	0.6×10^3
4	2.34	9.5×10^3	1.22	1.7×10^3
5	1.46	14.2×10^3	2.50	0.7×10^3
6	(0.66)	5.3×10^3	(0.47)	1.8×10^3
Mean b = 1.8*				

*All values less than 1.0 (in parentheses) are excluded. The values of b less than 1.0 theoretically are not possible except in a convergence.

Figure 3. Relationship of longitudinal (Δ) and transverse (o) variances of drogue positions to time in Port Valdez, Alaska, summer 1971.



The first run encountered difficulty with the drogues encountering ı island soon after release. As a result the variances actually de-rease when the drogues grounded, instead of increasing as required by ıe power law.

The values of effective diffusivity found in this experiment are an rder of magnitude lower than those found in Lake Michigan by Okubo and erber (1967). Okubo and Verber used current crosses suspended from loats which "feel" currents in only one stratum and disperse more early in accordance with the way a real pollutant diffuses. What has een established in this study is a lower limit to the rate of diffusion ı Port Valdez.

The theoretical value for the exponent (b) in $D^2 = at^b$ is 3.0)kubo 1962). Foxworthy et al. (1966) obtained values between 0.92 ıd 2.24 under varying conditions at the Orange County sewer outfall ı California. Okubo and Verber (1967) analyzed various sources and sserted that b = 2.5 fits a wide range of data. Therefore, it is felt ıat the value 1.8 obtained in Port Valdez is reasonable.

The integrating effect of a linear drogue which extends almost ırough the surface layer of brackish water can only be speculated on. erhaps the drogue assumes the mean velocity of all components of elocity contained in the water layer pierced by the drogue, but with time lag. It seems likely that local velocity shears with a scale ength less than the length of the poles will be less effective in mov-ıg the poles dispersively than they would be in dispersing a dissolved particulate pollutant.

CONCLUSION

Assemblages of drogues in Port Valdez dispersed at rates which in-rease with time. The rates of dispersal were found by computing the ıriance (D^2) of the distances transited by the drogues and fitting the esults to $D2 = at^b$. A mean value of 1.8 was determined for b with a ınge between 0.1 and 2.5.

Rates of change of the variance of drogue distances found imply ıat effective diffusivity in the direction of flow was between 3.2 x 10^3 ıd 14.2 x 10^3 cm^2/sec. Diffusivity in the transverse direction was etween 0.6 x 10^3 and 6.8 x 10^3 cm^2/sec. These values are an order of ıgnitude less than found by another type of drogue method in Lake ichigan (Okubo and Verber 1967) and establish lower limits to rates of iffusion in Port Valdez.

LITERATURE CITED

Foxworthy, J. E., R. B. Tibby, and C. M. Barsom. 1966. Dispersion of a surface waste field in the sea. J. Water Pollut. Control Fed. 38:1170-1193.

Nebert, D. L., R. D. Muench, and D. W. Hood. 1973. Dye dispersion studies. In D. W. Hood, W. E. Shiels, and E. J. Kelly (editors), Environmental studies of Port Valdez, p. 151-198. Occas. Pub. 3, Institute of Marine Science, University of Alaska, Fairbanks.

Okubo, A. 1962. Horizontal diffusion from an instantaneous point-source due to oceanic turbulence. Chesapeake Bay Institute Tech. Rep. 32, Johns Hopkins University, 124 p.

Okubo, A. and J. L. Verber. 1967. Drogue studies. In Federal Water Pollution Control Administration, Lake Michigan Basin: lake current, a technical report containing background information for water pollution control program. FWPCA, Chicago.