CHAPTER 83

PRELIMINARY RESULTS AND COMPARISON OF DYE TRACER STUDIES CONDUCTED IN HARBORS, ESTUARIES, AND COASTAL WATERS

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INTRODUCTION

Dye tracer studies have been conducted by the U. S. Naval Oceanographic Office in harbors, estuaries, and coastal waters during the past seven years. The purpose of the studies was to obtain data which could be used to (1) estimate the time (sometimes called the flushing time) required to remove or reduce to permissible concentrations the soluble part of any contaminant which may be released as a point source in a specific study area and (2) determine the temporal and spatial distribution of a contaminant released in a study area. The areas studied are listed in Table 1. Field reports (unpublished) have been prepared which describe in detail the results of each study.

A brief description of the tracers, equipment, and sampling techniques used, and a discussion of some of the results are presented.

GENERAL PROCEDURES

The general procedure consisted of releasing approximately 100 pounds of fluorescent dye into the water as a point source and then measuring dye concentrations until they decreased below the threshold of the sampling equipment. In addition to measurements of dye concentration, salinity, temperature, and current, observations were made at specific time intervals throughout the studies.

The tracers used in the studies were the organic dyes, fluorescein and rhodamine-B. These dyes have been used extensively as tracers and their characteristics have been described in detail by Feuerstein and Selleck (1963).

The sampling system used in the studies was essentially the same as that developed by the Johns Hopkins University (Carpenter 1960). The system consisted of a Turner Model III Fluorometer equipped with a continuous flow sample compartment. The fluorometer and auxiliary equipment were mounted aboard a small boat for continuous analysis of water samples as the boat traversed the dye patch. Water from selected depths was pumped through the fluorometer which continuously measured the dye content of the water, thus providing a comprehensive record of the temporal and spatial distribution of the dye.

Aerial color photographs of the dye patch were taken at specific time intervals after dye release. The photographs were used in conjunction with data collected by the survey vessel to determine the areal distribution of the dye.

DISCUSSION OF RESULTS

The dye tracer studies provided an estimate of the flushing time and described the spatial and temporal distribution of the dye within each study area only for the specific environmental conditions which existed at the time of the study (phase of tide, strength of current, etc.). Although the studies were particular single case studies for each area, comparison of the results revealed several facts about the behavior of the dye that could be applied to other types and amounts of contaminants released in the study areas under any environmental conditions. Two of the most significant results will be discussed briefly. The first concerns the observed relationship between the maximum dye concentration and the time elapsed after dye release. The plots of the logarithm of the maximum dye concentration versus the time after dye release are shown in Figures 1 through 5. Data collected during the first 30-60 minutes after release are not shown in the plots. These early data are considered unreliable because of the effects of the initial turbulence and mixing induced by the dye release and the boat moving out of the dye patch.

The figures show a simple straight line relationship between the two variables. Therefore, the maximum dye concentration at any time after release may be expressed by the equation:

$$C_m = C_1 \quad t^{-n}$$

where: C_m = maximum dye concentration
C_1 = concentration at one hour after dye release
t = time after dye release
n = proportionality factor

The proportionality factor (n), which will be called the time factor, is assumed to be a constant for each individual study area for $t > 1$ hour after dye release. This assumption has been verified for several of the areas where multiple tracer studies were conducted.

This relationship between maximum dye concentration and time after dye release provides an empirical basis for estimating the decrease in maximum concentration of other types and amounts of contaminants released in the areas studied.

The second result concerns the relationship between areas with similar physical characteristics and the rate of decrease in maximum dye concentration. Equation (1) indicates that $C_m \simeq t^{-n}$. The time factor (n) for each study area is listed in Table 1 and Figures 1 through 5. The study areas with similar physical characteristics (tide range, volume currents, etc.), are grouped together. The data in the Table and the figures show that the time factor (n) is the same for each study area within a group. In other words, the rate of decrease in maximum dye concentration is the same for areas with similar physical characteristics.

The study areas in Group 1 (Figure 1) are all small harbors with similar volumes, small tide range, and little or no current within the harbor. n = 2.5 in these areas. The areas in the second group (Figure 2) are nearly equal in volume and are characterized by narrow entrances opening into a larger embayment; n = 1.0 in this group. In the third group (Figure 3), both areas are large embayments and the data show n = 2.0 for each. The fourth group (Figure 4) represents studies which were conducted in relatively open coastal waters and n = 3.0 in each of these studies. The fifth group (Figure 5) consists of three rivers characterized by relatively strong tidal currents. There is no general agreement of the time factors in this group probably because of the difficulty encountered in making accurate measurements of the maximum concentration in a dye patch that was moving rapidly with the tidal currents.

This relationship between the rate of decrease in maximum dye concentration and areas with similar physical characteristics suggests an analog system for predicting the decrease in maximum concentration of contaminants released in other similar areas where tracer studies are not feasible.

At present, data from tracer studies conducted by other organizations are being reviewed to determine if the areas studied will fit into the preliminary classification scheme described, and to determine what physical characteristics are common to all the areas in a specific group. The tracer studies reviewed to date are listed in Table 2. Data from a study made in Chesapeake Bay, a large embayment (Pritchard and Carpenter, 1960) show n = 2.0 which agrees with the time factors for the other large embayments listed in Group III. Data obtained in dye studies conducted in the sea off Tokai-Mura (Okubo, et al., 1957, Nanitti and Okubo, 1957) in the sea off Cape Caraveral (Chesapeake Bay Institute, 1962). and in the Great Lakes (Noble, 1961) all show n = 3.0. These study areas are in relatively open coastal waters and the time factors agree with those of the coastal water studies listed in Group IV. However, the time factor n = 2.0 computed for a study conducted in the coastal waters of the Irish Sea (Seligman, 1955) does not agree. The studies reviewed show a general agreement with the preliminary classification, however, data from areas covering a wide range of physical characteristics must be examined before a completely reliable classification system could be established.

CONCLUDING REMARKS

The studies indicate that dye tracer techniques are effective for estimating the flushing time and describing the temporal and spatial distribution of a contaminant in a specific area for the environmental conditions existing at the time of the study.

Although the discussion of the results of the tracer studies was principally subjective, the relationships concerning the maximum dye concentration indicate the possibility of developing a simple method for predicting: (1) the decrease in maximum concentration of any type or amount of contaminant released in the study areas during any environmental conditions and (2) the decrease in maximum concentration of a contaminant in other similar areas where tracer studies are not feasible.

However, more widespread tracer studies are needed to determine the validity of the classification system presented and repeated tracer studies are needed in the same area to determine the constancy of the time factor for a wide range of environmental conditions.

TABLE I
SUMMARY OF TRACER STUDY DATA

	LOCATION	TIME FACTOR
I.	MAYPORT BASIN JACKSONVILLE, FLORIDA	2.5
	KEY WEST HARBOR FLORIDA	2.5
	PEARL HARBOR, HAWAII (SOUTHEAST LOCH)	2.5
II.	LONG BEACH HARBOR CALIFORNIA	1.0
	WEYMOUTH-FORE RIVER QUINCY, MASSACHUSETTS	I.0
III.	GALVESTON BAY TEXAS	2.0
	SAN DIEGO BAY CALIFORNIA	2.0
IV.	NEAR BERMUDA	3.0
	NEAR NEW PROVIDENCE ISLAND, BAHAMAS	3.0
V.	PISCATAQUA RIVER PORTSMOUTH, NEW HAMPSHIRE	I.4
	COOPER RIVER CHARLESTON, SOUTH CAROLINA	2.0
	PASCAGOULA RIVER MISSISSIPPI	3.0

TABLE 2
TRACER STUDIES REVIEWED

LOCATION	TIME FACTOR
CHESAPEAKE BAY	2.0
OFF CAPE CANAVERAL	3.0
OFF TOKAI-MURA	3.0
GREAT LAKES	3.0
IRISH SEA	2.0

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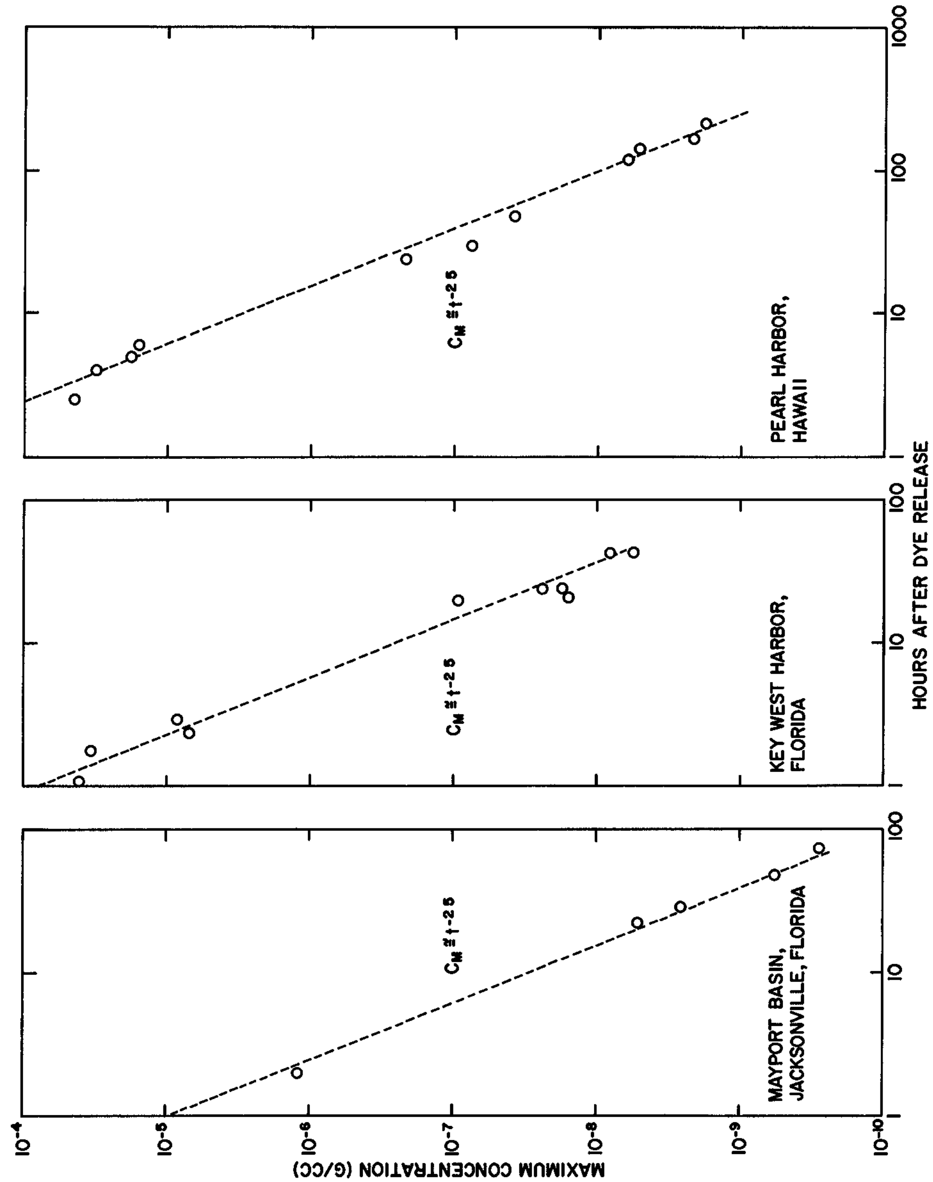

Fig. 1. Decrease in maximum concentration with time, Group I.

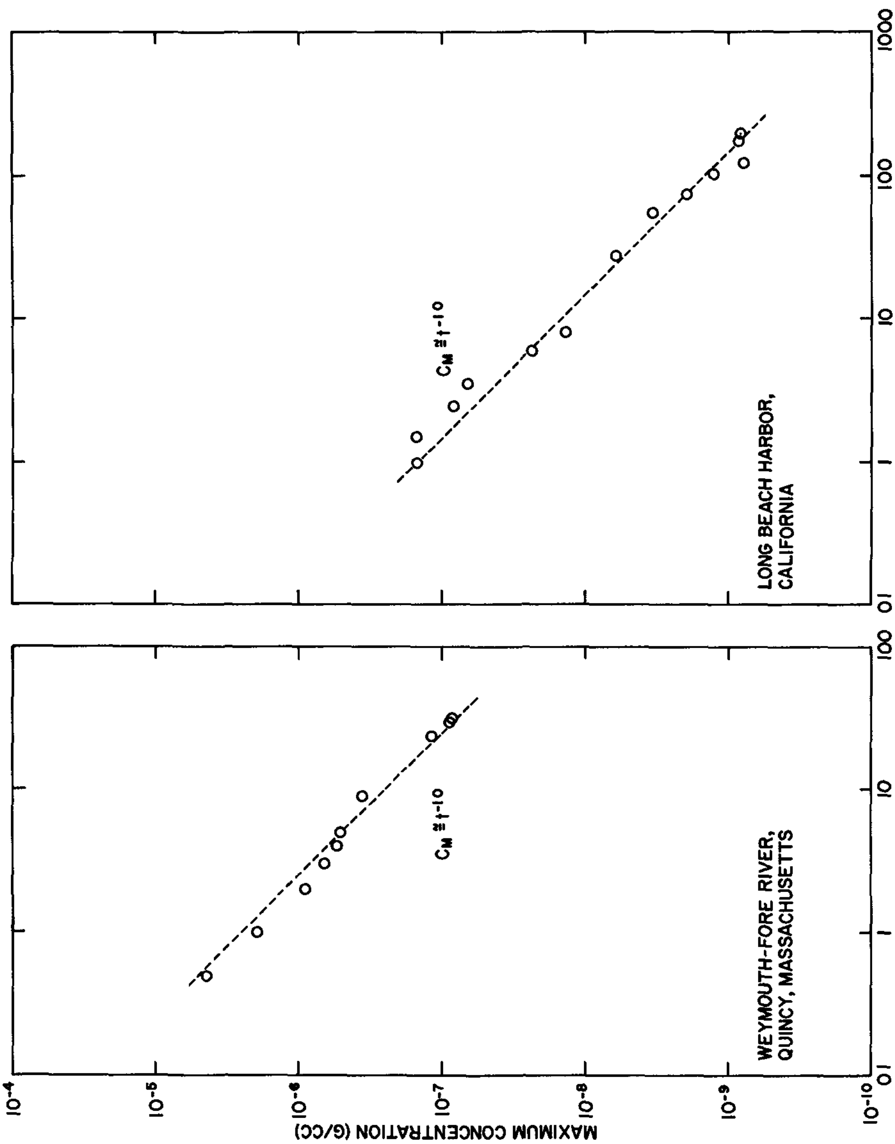

Fig. 2. Decrease in maximum concentration with time, Group II.

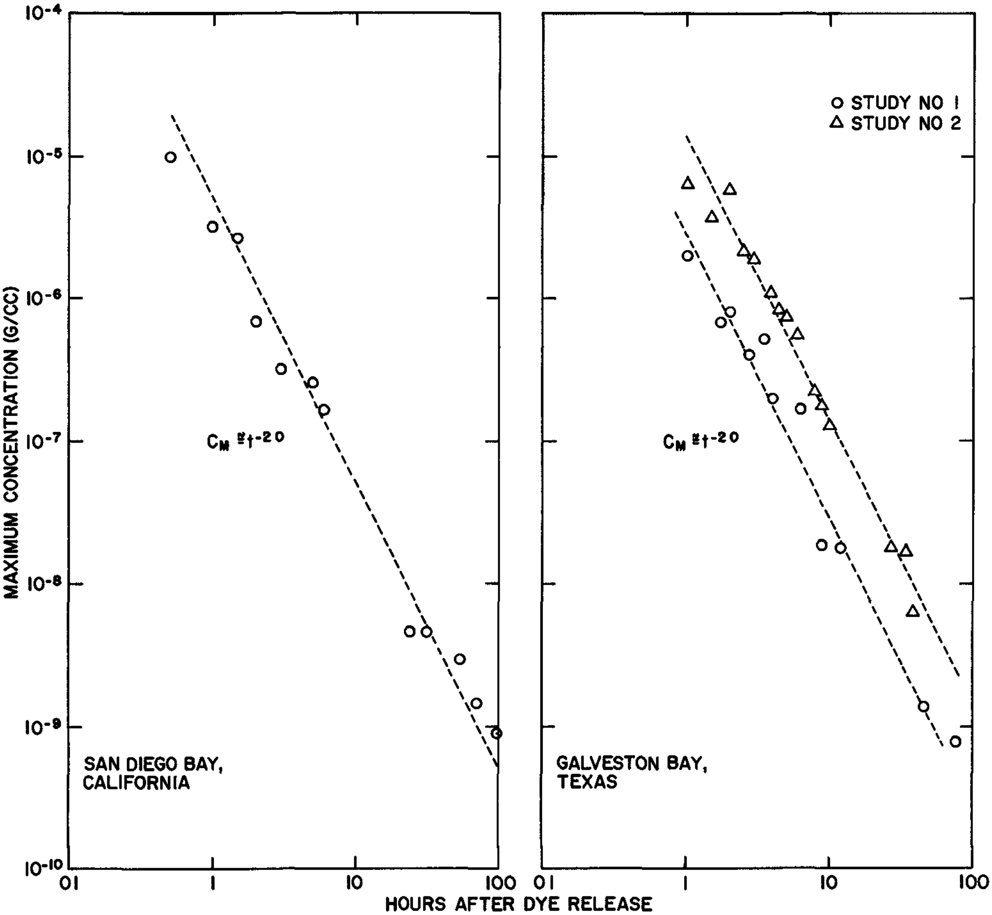

Fig. 3. Decrease in maximum concentration with time, Group III.

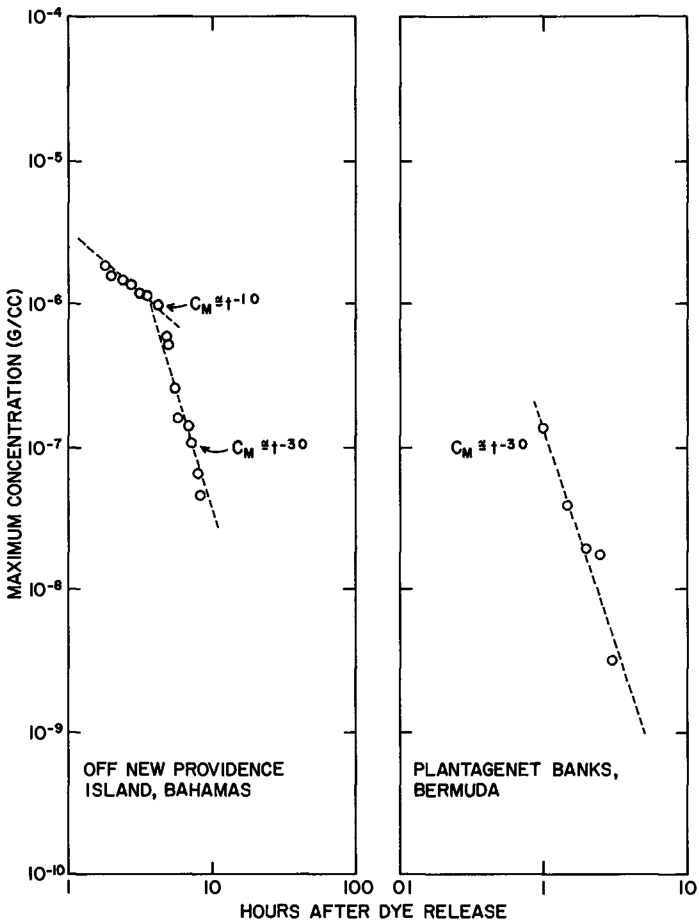

Fig. 4. Decrease in maximum concentration with time, Group IV.

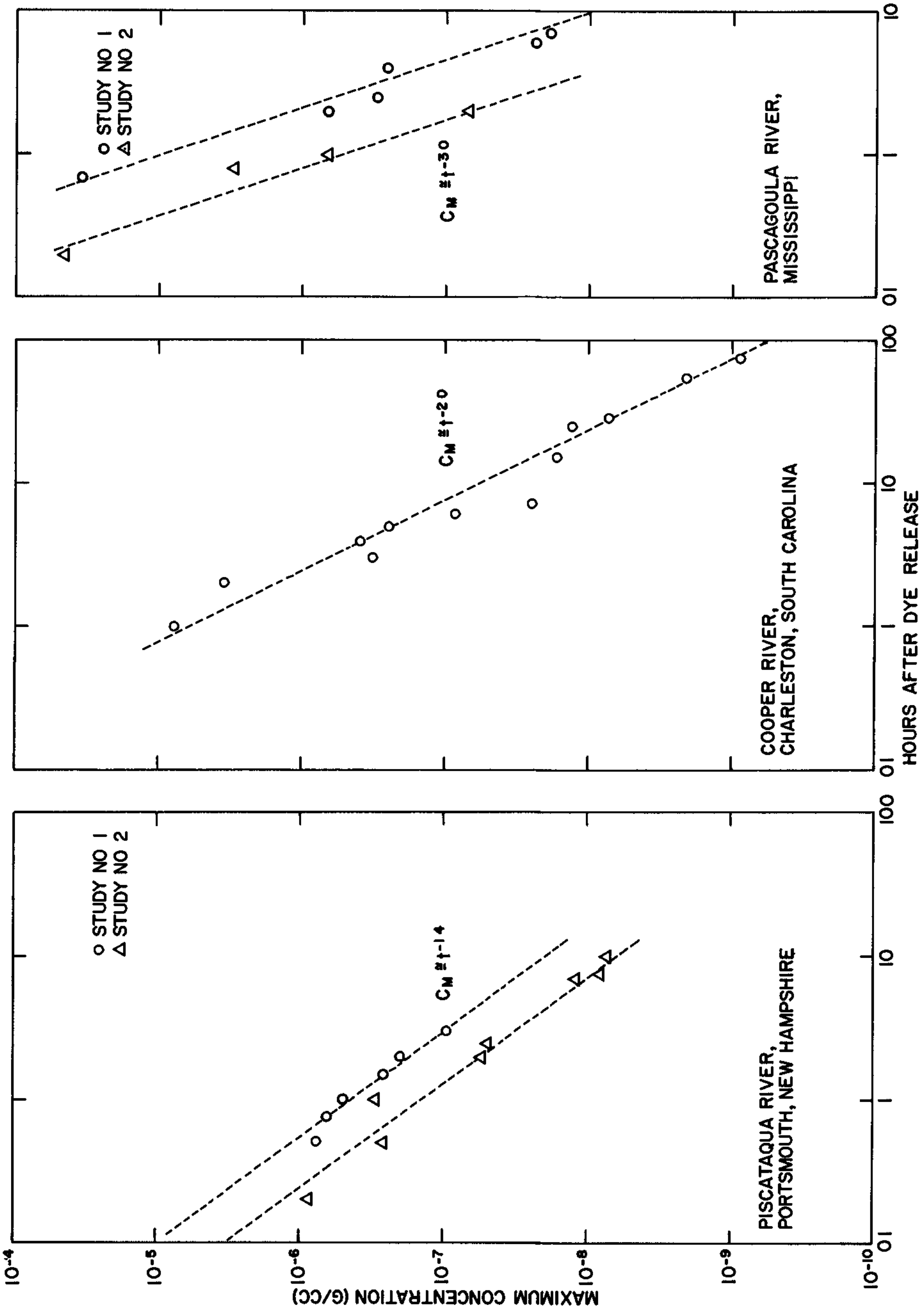

Fig. 5. Decrease in maximum concentration with time, Group V.