FLUSHING STUDY OF SOUTH BEACH MARINA, OREGON

by Richard J. Callaway[1]

INTRODUCTION

Recent increases in recreational and small commercial craft activities have resulted in the construction of many new marinas. Local, state and federal government must evaluate applications for marina construction permits. Little information exists on ecological impacts of marinas or of construction events such as dredging and spoil disposal.

This report concerns one aspect of the marina permit evaluation process: water quality impacts related to marina circulation and flushing efficiency. These physical properties vary with the wind, tide range, water density and physical dimensions of a marina. Water quality is affected by the degree of flushing, and sediment redistribution by currents. Detrimental water quality can determine, e.g., the fate of migrating juvenile fish and benthic organisms (5,7).

Ecological studies of marinas are few. The most comprehensive have been performed on Marina del Rey, California (3, 15, 16, 17, 22). Slotta and Noble (21) discussed the use of benthic sediments as indicators of marina flushing in several Pacific Northwest marinas. Puget Sound marina water quality studies have also been conducted (10, 11, 24).

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MARINA MODEL STUDIES

Most mathematical studies of marina circulation and flushing have been concerned with vertically well-mixed waters in one and two dimensions (1, 2, 4, 6, 18, 20).

Hydraulic model studies of small harbors provide an alternative method of assessing flushing ability, although not without deficiencies related to scale distortion. Several hydraulic model studies of Pacific Northwest marinas have been conducted by Nece and Richey and their associates at the University of Washington (9, 12, 13) and by Slotta and others at Oregon State University (1, 20, 21).

Because of the small size of most Pacific Northwest marinas, use of numerical models employing finite difference grids or finite elements is not always practical. In order to utilize the numerical method to its best advantage, very small grids would need to be used; for finite difference analogs employing explicit solutions this would in turn require small time steps less than the grid size, Δx, divided by the speed of a shallow water wave, $\sqrt{gh}$, for a 1-dimensional simulation. For a 328 ft (100 m) grid size in, say, a 20 ft (6 m) deep marina (depth + 3.3 ft (1 m) tide amplitude) the time step would need to be less than 13 seconds. Smaller grid sizes or greater depth, h, require proportionately smaller time steps and increased computer time.

The Oregon marinas examined at Oregon State University used Froude scale models as did those constructed at the University of Washington. All of the model studies (except that reported by Nece _et al._, 13) were site-specific.

One advantage of an hydraulic model over a numerical one is that small scale operations relating to mixing can be readily observed and photographically recorded. These phenomena approximate mixing processes which take place in the prototype. No attempt has been made to study vertical exchange processes in either the numerical or hydraulic models. Rather, time and space averages were taken; the water column is assumed well mixed in the vertical. This assumption prevents the reproduction of vertical or horizontal convection currents.

FIELD SURVEYS

Dye releases have been used to determine flushing rates in Florida finger canals (2, 8, 23). Slotta and Tang (20) released dye in Oregon's Chetco estuary boat basin and compared results with an hydraulic and a finite element model. Discrepancies between field and hydraulic model results were due to the difficulty of obtaining the proper density differences between dye and the receiving water in the hydraulic model. Depth-averaged concentration-vs.-time curves were similar, however.

In the field experiments to be described, dye as a tracer was distributed throughout the marina during the middle stage of a flood tide. The last two hours of the flood tide were used to permit the dye to continue mixing. An initial average dye concentration, C_o, was achieved at maximum high tide; ideally, this concentration remains constant on the following ebb tide, while dye mass decreases. Assuming no return of dye on the next flood tide, the mass of dye in the marina remains constant while the concentration decreases with an increase of volume during the flood.

These assumptions can be expressed as follows. For dye mass, M, at concentration, C, and representing increasing volumes as +, decreasing as -, and constant as o, then for flow Q, and volume V:

$$Q^{+},\ V^{+} \xrightarrow{\text{Flood}} M^{o},\quad C^{-}$$

$$Q^{-},\ V^{-} \xrightarrow{\text{Ebb}} M^{-},\ C^{o}$$

Then, on a flood tide, mass is constant but $C^{-} \rightarrow M^{o}/V^{+}$; on an ebb, $M^{-} \rightarrow M^{o} - C^{o}V^{-}$ where M^{o} is the mass at the end of a flood tide. Note that it is assumed that the dye is uniformly mixed throughout the basin at the time of initial high tide.

For the case of no direct fresh water inflow, the volume of water present in a marina can be evaluated in terms of a mean tide level volume, V_o, and variations about the mean. For a mean low tide volume $V_l = V_o - A_oR/2$, where A_o is mean marina surface area and R is the tidal range from mean low to mean high water.

The tidal prism volume is $V_p = V_h - V_l = A_oR$. This is the amount of water on an ebb tide carrying with it a mass M (for the first ebb) at concentration C_o. At the end of the ebb the mass is, as above,

$$M_1 = M_o - C_o(A_oR).$$

On the following flood tide, the concentration decreases; at the end of the flood,

$$C_1 = M_1/(A_o(R+d)),$$

where d = depth to mean low water level while the mass is unchanged. There is a stepwise decrease in both M and C; however, the time change between constant values is gradual rather than abrupt and C and M are out of phase by 90°. It follows that the concentration after the i^{th} flood cycle is $C_i = C_o(V_l/V_h)^i$.

This relationship can be explored through analysis of a first order differential equation. The rate of change of concentration is assumed proportional to the concentration present:

$$dC/dt = -(Q/V)C$$

where $Q = \frac{1}{2}A_o R\omega \sin(\omega t)$

$V = V_o + \frac{1}{2}A_o R \sin(\omega t + \alpha)$,

and $\omega = 2\pi/T$ is the frequency at tidal period T and α is a phase angle.

Solving by numerical differentiation

$$C_{t+1} = C_t - \frac{QC}{V}_t \Delta t,$$

where the subscripts are time and Δt is the time step. The t_i are in any given time units, not necessarily tidal cycles, with the restriction that on an ebb cycle $C_{t+1} = C_t$. The equation can also be solved by direct integration.

<u>South Beach Marina Characteristics</u>

The entrance to South Beach marina is 1.5 nautical miles (2.8 km) upstream of the end of the north jetty at Newport, Oregon (Figure 1). Approximate marina dimensions are: length, L, 1574 ft (480 m); width, W, 623 ft (190 m); depth, d, at mean tide level, 13.4 ft (4.1 m) resulting in a MTL volume, V_o, of 1.34×10^{-7} ft^3 (3.74×10^5 m^3) and a mean low tide volume, V_1, of 1.04×10^7 ft^3 (2.90×10^5 m^3). Mean tide range, R, is 6.0 ft (1.83 m) resulting in a mean tidal prism volume, $V_p = R \times L \times W$, of 6.07×10^6 ft^3 (1.7×10^5 m^3). The entrance width is 157 ft (48 m) resulting in a mean cross-sectional entrance area, A, of 2118 ft^2 (197 m^2).

The marina is designed to hold 600 boats. At the time of the field work no boat slips or piles were in place. Dredge spoil was disposed of on the east bank of the marina. The marina breakwater jetty restricts rapid flow-through.

South Beach Marina Hydraulic Model Studies

An hydraulic model study of South Beach marina was made by Richey and Skjelbreia (19). The model used a 1:10 horizontal/vertical distortion ratio; Froude scaling was employed with the following scale ratios: horizontal length - 1:480; vertical length - 1:48; velocity - 1:6.93; time - 1:69.3. The prototype tidal cycle was taken as 12.4 hours which required 10.74 minutes to reproduce in the model. Sinusoidal tides were used for 0.9, 1.8 and 2.7-m ranges. Model water density was uniform; boat slips and pilings and wind stress were not modeled.

A 20% solution of rhodamine-WT diluted 1:100 was used as a tracer. Thirty ml of dye was completely mixed in the model at high water location. A Turner Model 110 fluorometer was used to determine relative concentration at the end of four tide cycles.

This procedure was augmented by time-lapse photography of the loss of water soluble dye with time. The photos were analyzed by a densitometer to obtain relative concentration versus time. Exchange coefficients, defined as $E = 1-(C_i/C_o)^{1/i}$, were determined from both the dye and densitometer data. Here, C_i = concentration at the i^{th} tidal cycle and C_o is initial concentration. Exchange coefficients thus calculated are shown for the 5.9 ft (1.8 m) tide in Figures 2 and 3. Figure 2 shows E-values at the end of four cycles. These are averaged values and range from about 0.15 in the southwest corner to 0.5 in the northeast corner. Low values correspond to relatively low flushing while higher values indicate greater flushing. This is shown in Figure 3, where individual C_i/C_o values are 0.35 for station 3 and 0.1 for station 4. This corresponds to E = .23 and E = .44 for stations 3 and 1, respectively, which is in the range of the values given in the previous Figure.

The main conclusions of the hydraulic model study were as follows:

1. The basin had good hydraulic characteristics except for poor exchange in the south corners.
2. Good exchange is due to strong currents in the main channel passing the marina entrances which can introduce turbulent eddies on flood tide and prevent recirculation on the ebb.
3. The currents past the entrance improve the exchange coefficient by about 25% over that were the entrance situated on a quiet bay.

Field Float Studies

Weighted poles of 6, 8, 10, and 12 ft (1.83, 2.44, 3.05, and 3.66 m) submerged length were released and followed on January 17-18, 1979, in conjunction with a dye release; pole positions were fixed by sextant. Easterly winds ranged from 3-10 (1.5-5 m/s) on the first survey day which was conducted on an ebb tide; 10-knot winds determined the main direction of all pole trajectories during this ebb cycle although a northwest water current component toward the entrance was present. Tide decreased from a maximum (LHW) height of 6.9 ft to 3.9 ft (2.1 m to 1.2 m), about mid-tide. Maximum pole velocities observed for the 6 and 8 foot poles were 0.8 and 0.9 fps (26 and 27 cm/s), respectively.

Winds were less than 3 knots from the west on the January 18 survey. Tides increased from 6.2 ft (1.9 m) to 7.5 ft (2.3 m) (HHW). Although this study was only conducted for a short time, pole trajectories show that surface water near the entrance had a net outward direction while the deeper layer showed inward motion. Thus, there was some flushing on the incoming tide in the upper layers.

Field Dye Studies

Rhodamine-WT was released for about one hour over the entire marina (Figure 4) starting about four hours before slack water on flood tide. Visual observations from the U.S. Highway 101 bridge at Newport and a light plane did not reveal any obvious high or low surface dye patch concentrations.

Fifty-one lbs (23 kg) of 20% dye was diluted with 50 gal (190 l) of seawater to approximate receiving water density from a 55 gal (210-l) drum; it was discharged at about 0.8 gal/min (3 l/min). Two methods of release were used. On the first survey, a 15 ft (4.6 m) hollow aluminum pole with a horizontal discharge tube at the bottom was raised and lowered as the dye was released. The outboard motor vessel made right angle paths throughout the marina. On the second survey, a garden hose was towed at about 45° from the surface to bottom behind the boat throughout the water column; discharge ports in the hose at about 1.5 ft increments allowed for more even vertical distribution of the dye than occurred on the first survey.

At the locations shown in Figure 4 hourly samples at the surface, mid-depth and about 1.5 meter from the bottom were drawn from a continuous flow hose-pump arrangement. Samples were taken at hourly intervals for the first 14 hours and at mid and maximum high and low tides thereafter until background levels were approached.

Samples were analyzed on board by a Turner 111 flow-through fluorometer fitted with 546-μ excitation and 590-μ emission filters. Samples for analysis in the laboratory were collected in 125-ml screw-cap containers after local equilibrium was reached as indicated on the field fluorometer. The Turner Designs fluorometer was used in the laboratory. Frequent field calibration was made; laboratory standards were used before and after each run, values reported here are from the laboratory analyses.

FIELD STUDY RESULTS

The 1978 study was similar to that of 1979 except for the following differences: 1) average tide ranges were 7.9 and 4.9 ft (2.4 and 1.5 m), respectively; 2) water column density was different, with a greater rate of change of density with depth for the 1978 study; 3) the method of introducing the dye was different.

Stratification was slight on each study, the main differences being due to temperature. Salinity and temperature-depth profiles showed a gradual decrease in temperature from 15.6°C to 14.6°C and increase in salinity from 31.6 to 32.1 °/oo from surface to bottom for 1978.

1978 Survey

Attempts to distribute dye evenly throughout the water column were not completely satisfactory. Figure 5 shows surface, mid and bottom dye concentrations at station 6 (refer to Figure 4). The surface and middle concentration were nearly equal at about 1400 on 9/15/78, but the bottom sample was initially quite low; all samples approached equality after about 0600 on 9/16/78. Surface concentrations for all 6 stations over the duration of the experiment showed similar concentrations except for station 1, which decreased rapidly to about 1800 on the first day. Bottom concentration with time showed station 1 having lower concentrations than all the others until 2200 (9/15) when, again, the concentration lines merged. Stations 2 and 3 showed several spikes which were not apparent in the other values.

Figure 6 shows values of C_i/C_o averaged for all stations. The modified tidal prism and numerical model results are also shown. Considering the variability of the dye patches, the first 7 hours are in reasonable agreement. A rapid decrease in concentration is shown from hours 7 to 12 in the models and in the field data. The latter, however, continue to show decreases to about hour 18.

The 1978 field data can also be compared with the hydraulic model results for the 8.8 ft (2.7-m) range tests. Exchange coefficients in the hydraulic model ranged from 0.44 to 0.52. Interpolation between the 6 ft (1.83 m) and 9 ft (2.74 m) ranges give E = 0.44 for the 8 ft (2.4 m) range found in the field. The exchange coefficient based on the prism method is 0.5 for the 8 ft range. This gives C_i-values of 1, 0.55, 0.30, ... on alternate high tides starting with $C_i/C_o = 1$. Field, hydraulic and mathematical model results all clearly show rapid flushing for this tide range. The hydraulic and mathematical model results are essentially equivalent but underestimate the dye removed when compared with the field study.

<u>1979 Survey</u>

For the 1979 survey the sampling station location was essentially the same as before except that station 3 of the 1978 survey was eliminated (Figure 4).

Plots (not shown) of all stations at the surface, middle and bottom show better initial mixing than in 1978. Station 1, in the NE corner, initially showed higher concentrations than the other stations but quickly merged with the rest. All data showed an increase in C_i/C_o ratios from about hour 3 to 7 (ebb cycle) while values at station 4 indicated recirculation south along the west side of the marina.

The hydraulic model results (19) show an average interpolated exchange coefficient of 0.3 for the 6 ft range. The high tide C_i/C_o-values at station 1 in the model and field are close; there is an initial rapid decrease in concentration to about $C_i/C_o = 0.2$ followed by a gradual decrease to 0.1 at the fourth tide cycle. Figure 7 shows the average C_i/C_o results for the hydraulic model as taken from Figure 3, and the mathematical model values.

For the average results, the discrepancy is rather large giving V_l/V_h = 0.64 which results in alternate high tide C_i/C_o values of 1, 0.64, 0.41 ... After hour 12, on the second ebb tide, when the concentration should remain constant, there was only a slight straightening out of the curve; the predicted and observed curves merged after the second flood tide.

Comparisons of Figures 6 and 7 show that normalized concentration-time curves were quite similar with respect to the sharp decline during the first flood cycle. The 1979 curve shows a steeper exponential decrease toward background concentration.

SUMMARY AND CONCLUSIONS

South Beach marina has a single entrance and is uncomplicated geometrically; it has free exchange with the main navigation channel where rather large currents develop during ebb and flood tides.

Mathematical and hydraulic models results agreed well when exchange coefficients were averaged over the entire hydraulic model.

Flushing efficiency near the marina entrance is about twice as great as the inner harbor as indicated by the hydraulic model over four high-tide cycles. Field results show similar spreads although variations are more extreme among stations.

Neither the hydraulic nor mathematical models successfully reproduced early flushing events; both underestimated the first flood decrease in concentration by about 30-40%. Thereafter the predicted and observed curves paralleled each other, although the model-predicted curves remained higher. In terms of pollutant concentrations, both model results were more conservative.

Hydraulic model studies successfully predicted that the South Beach marina would have satisfactory exchange because of the strong currents moving past the entrance. These entrance currents undoubtedly provide significant transfer processes through vortex motion and gyre generation. It is unlikely that a marina of similar dimensions would be as well flushed if it were sited in a less active environment.

The mathematical and hydraulic model comparison raises doubt as to the need for hydraulic model studies of small marinas <u>if</u> one can be content with conservative predictions. For marinas of similar dimension in similar locations, good approximations of flushing efficiency can be made in a matter of minutes using simple box-model assumptions. However, these results cannot be extrapolated to other marinas with multiple entrances, significantly different width-to-length ratios or environmental settings.

ACKNOWLEDGEMENTS

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Appendix II. -- Notation

The following symbols were used in this paper:

A = cross-sectional or planform area

C = concentration

d = mean tidal depth

E = exchange coefficient

g = gravity

h = maximum depth, shallow water wave

HHW = higher high water

i = tide cycle

L = marina length

LHW = lower high water

M = dye mass

MTL = mean tide level

R = tide range

T = tidal period

V = volume

W = marina width

α = phase angle

Δx = grid length

ω = frequency (= $2\pi/T$)

Subscripts

h = high water

l = low water

o = mean tide

p = tidal prism

t = time step

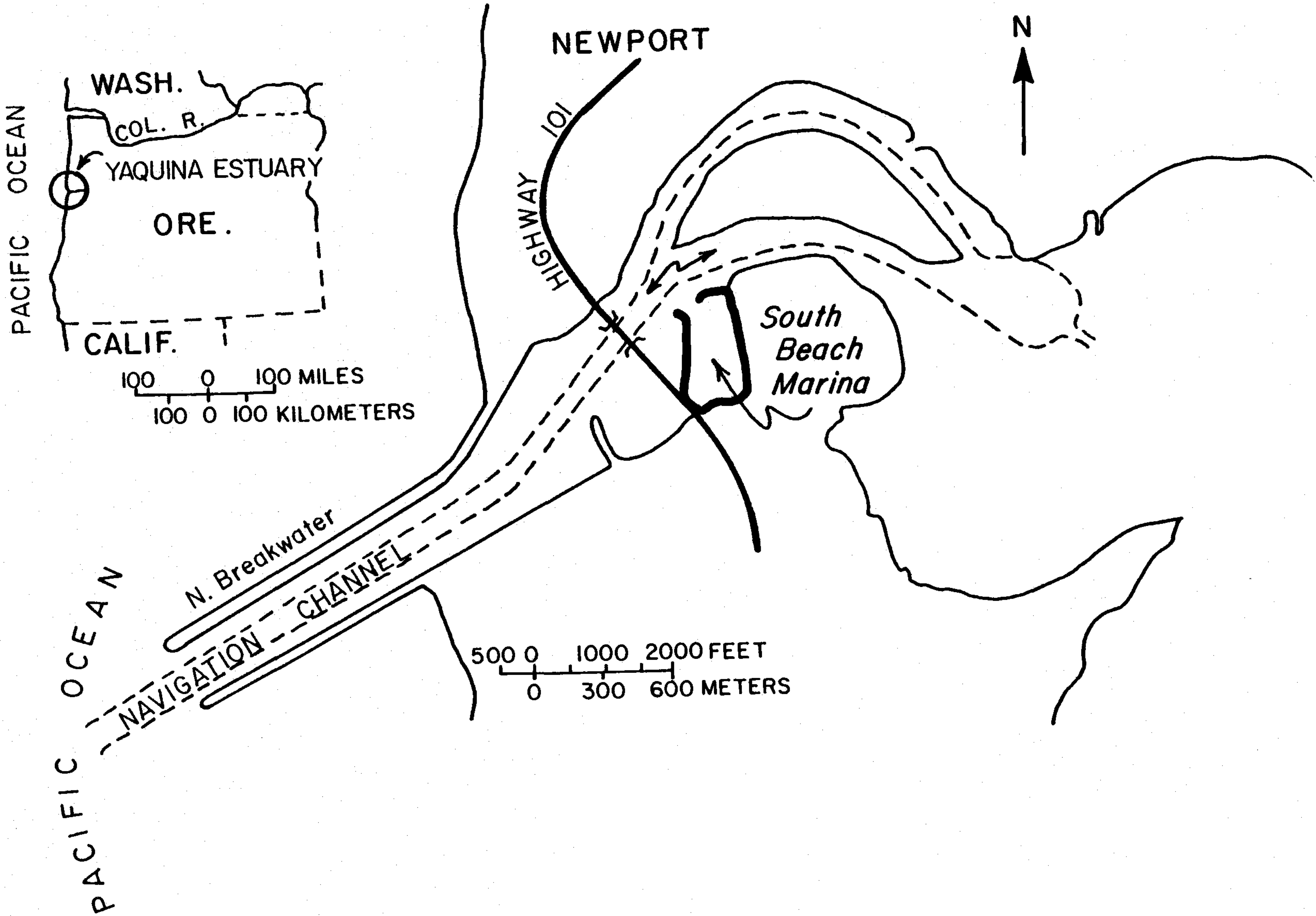
Superscripts

\- = denotes decreasing values

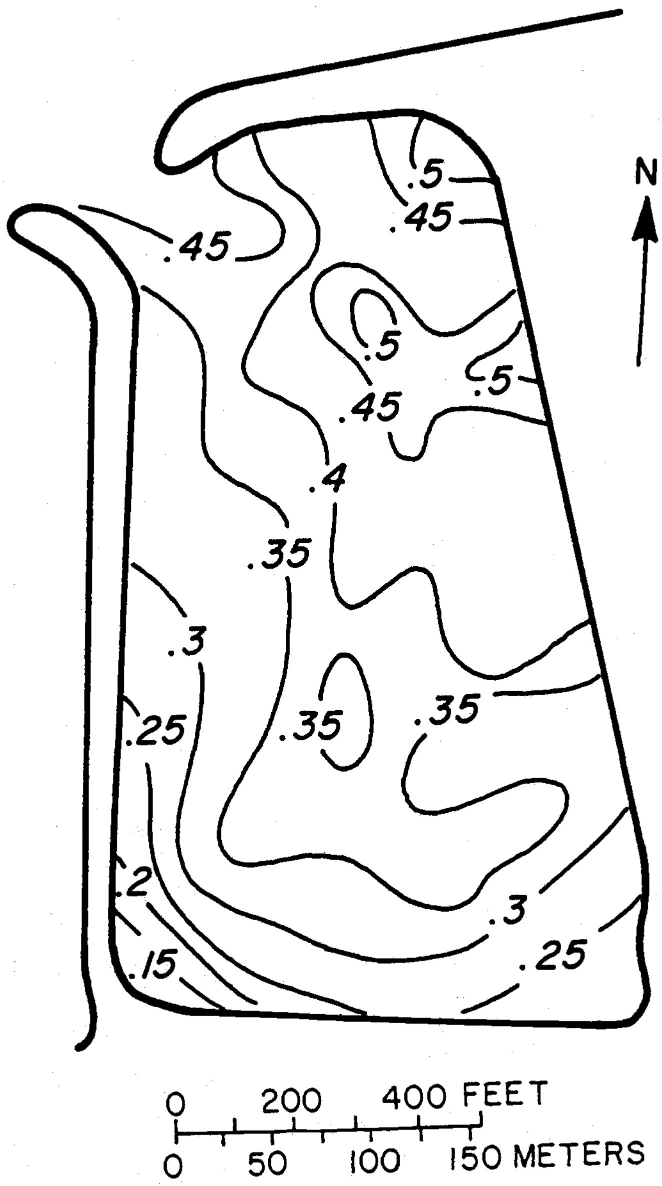
\+ = denotes increasing values

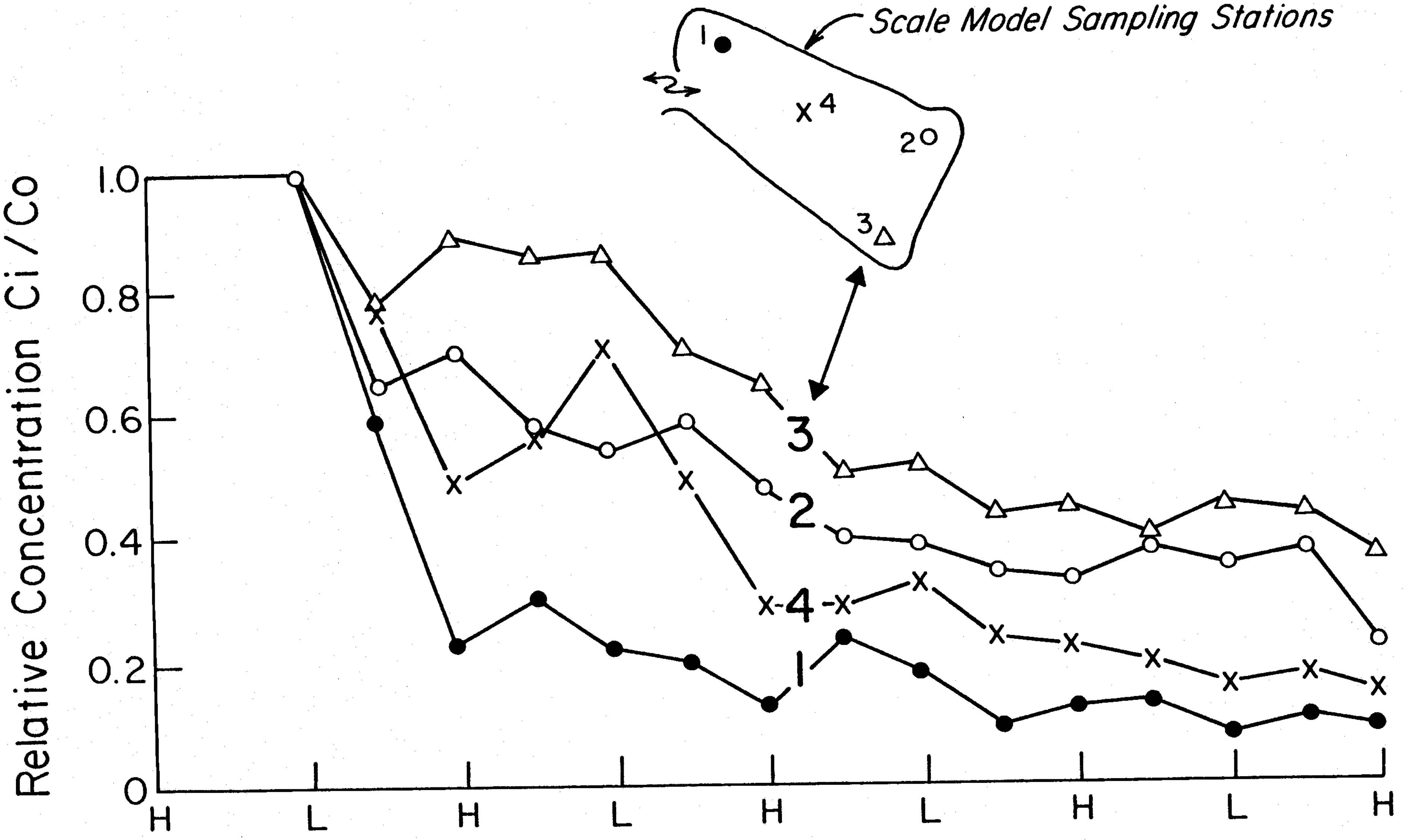
0 = denotes constant values

LIST OF FIGURES

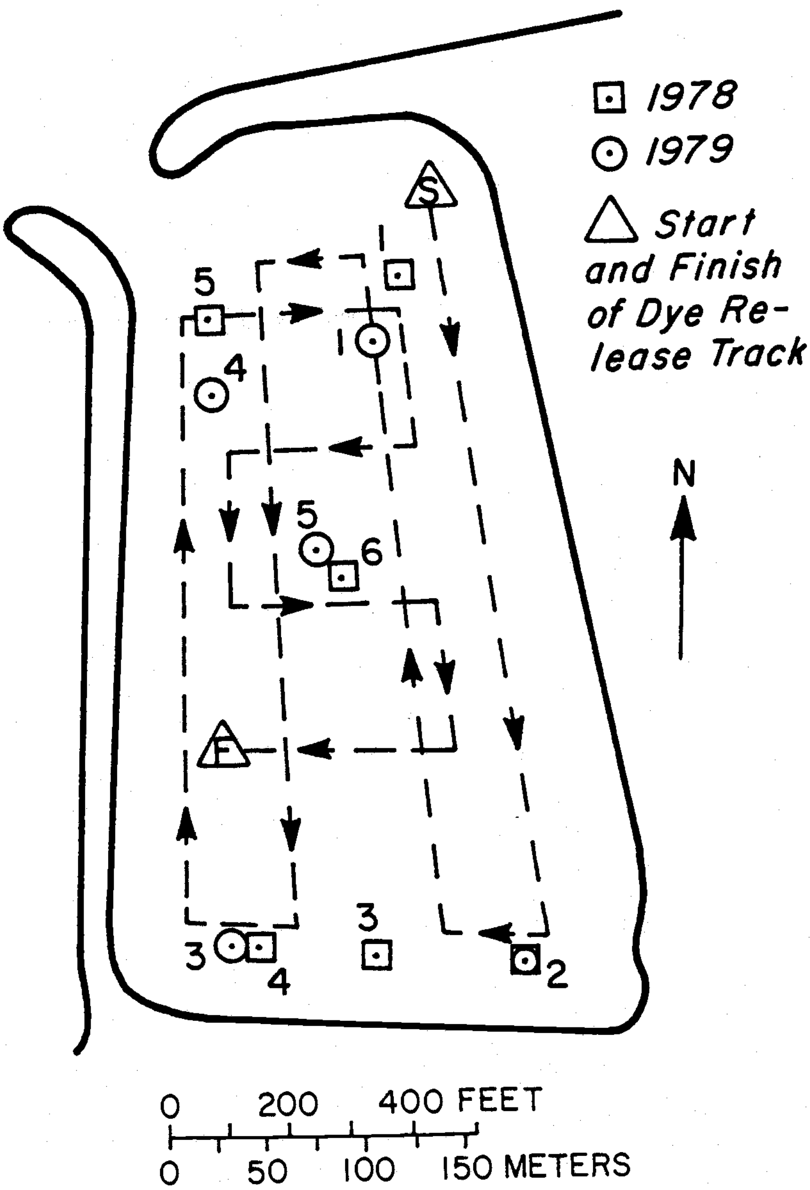

NEWPORT
N
WASH.
COL. R.
YAQUINA ESTUARY
ORE.
CALIF.
PACIFIC OCEAN
100 0 100 MILES
100 0 100 KILOMETERS
HIGHWAY 101
South Beach Marina
N. Breakwater
NAVIGATION CHANNEL
500 0 1000 2000 FEET
0 300 600 METERS
PACIFIC OCEAN

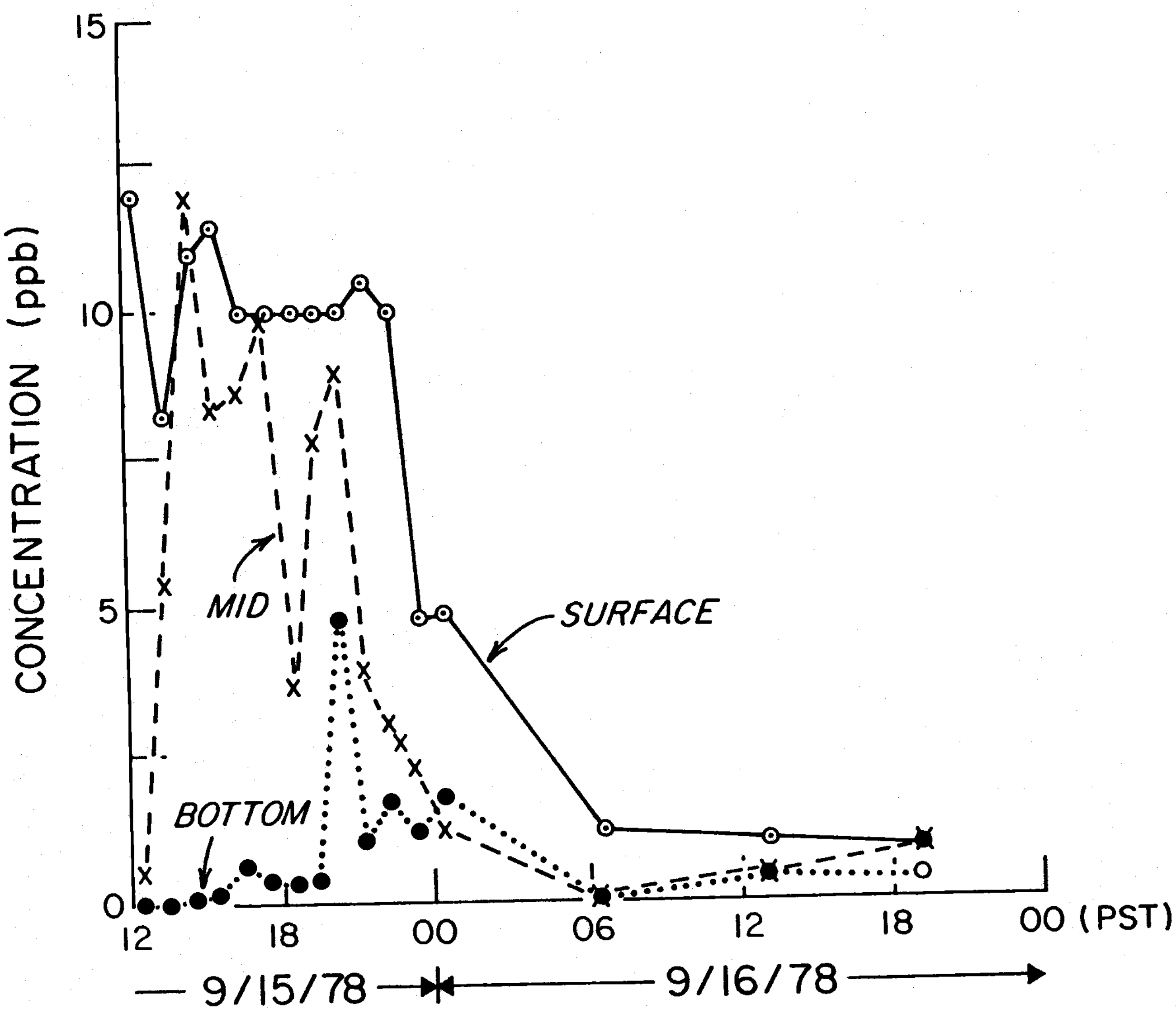
CALLAWAY, FIG 12



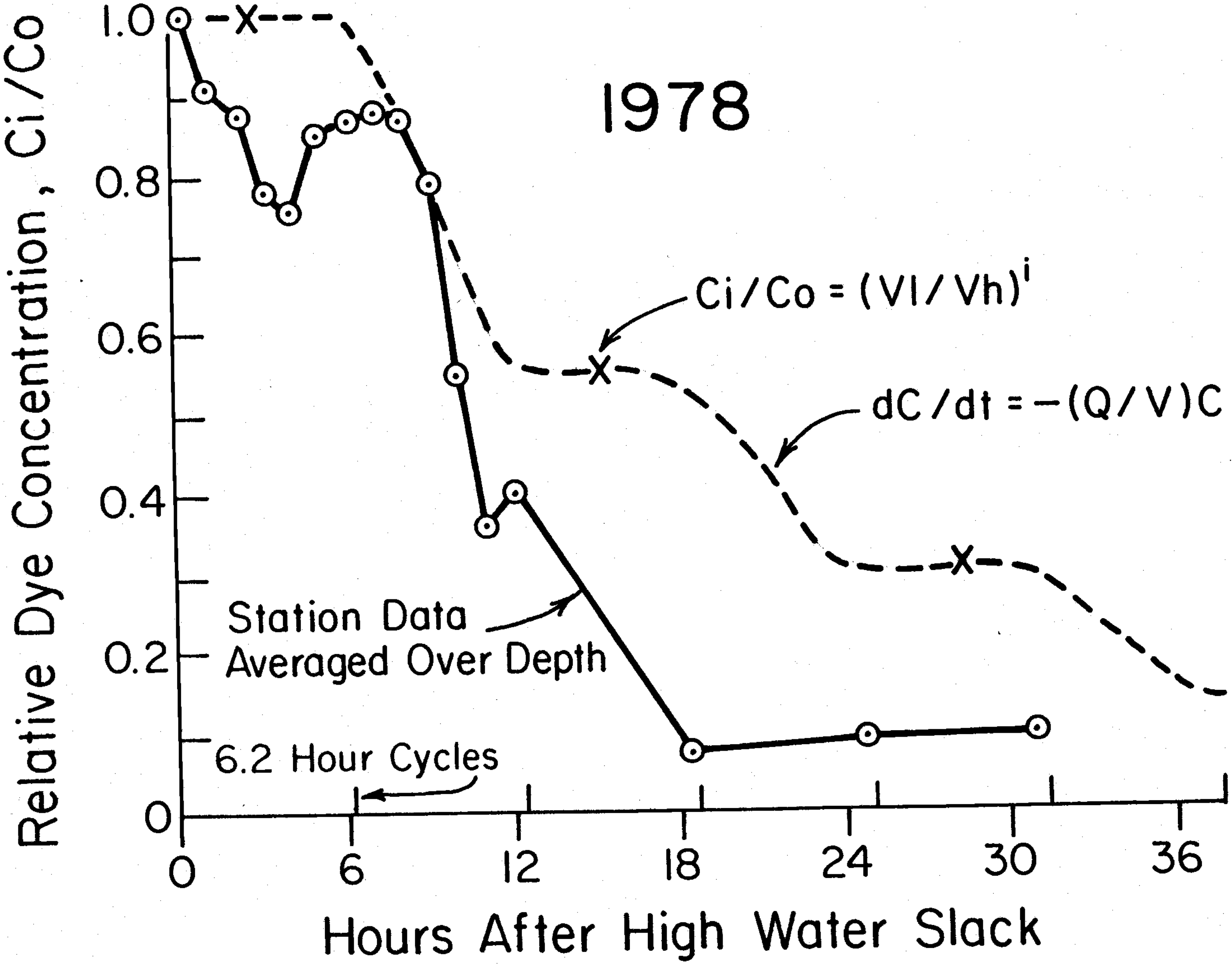


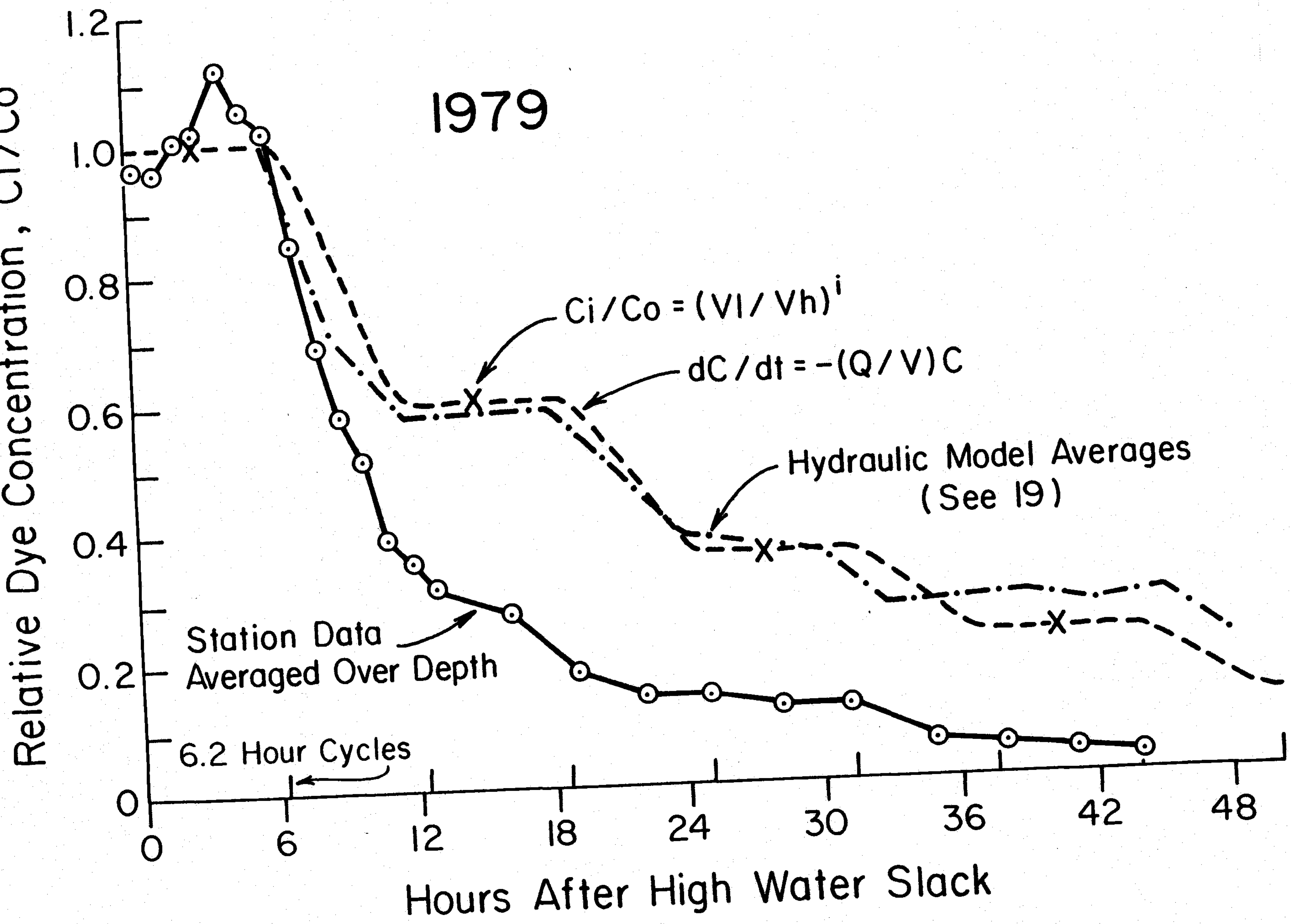
Scale Model Sampling Stations
1
4
2
3
Relative Concentration Ci / Co
1.0
0.8
0.6
0.4
0.2
0
H
L
H
L
H
L
H
L
H
3
2
4
1


1978
1979
Start and Finish of Dye Release Track
N
S
F
1
2
3
4
5
6
0 200 400 FEET
0 50 100 150 METERS



CONCENTRATION (ppb)
15
10
5
0
12
18
00
06
12
18
00 (PST)
9/15/78
9/16/78
SURFACE
MID
BOTTOM


1978
Ci / Co = (Vl / Vh)^i
dC / dt = −(Q / V)C
Station Data
Averaged Over Depth
6.2 Hour Cycles
Relative Dye Concentration, Ci / Co
1.0
0.8
0.6
0.4
0.2
0
0
6
12
18
24
30
36
Hours After High Water Slack


1979
Relative Dye Concentration, Ci/Co
1.2
1.0
0.8
0.6
0.4
0.2
0
Hours After High Water Slack
0
6
12
18
24
30
36
42
48
Ci/Co = (Vl/Vh)^i
dC/dt = -(Q/V)C
Hydraulic Model Averages
(See 19)
Station Data
Averaged Over Depth
6.2 Hour Cycles