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HUMBOLDT BAY WASTEWATER CIRCULATION STUDIES, APRIL OF 1979

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INTRODUCTION

Dye studies in previous years have looked at water movement in Humboldt Bay in relation to sewage treatment plant discharges (NCRWQCB 1974, 1977, 1978). Those studies, however, did not measure rates of travel and dilution of water masses in Arcata Bay as related to shellfish harvest. This study was more intensive in hopes of gaining a better understanding of the behavior of STP effluent discharges in Humboldt Bay, specifically in Arcata Bay. The general goal of this study was to determine the threat to shellfish harvesting areas (both sport and commercial) from sewage plant discharges. Participating agencies were the North Coast Regional Water Quality Control Board (State of California), the California Department of Water Resources, and the Northeast Technical Services Unit of the Food and Drug Administration. The specific objectives for this study were:

1) to determine the spread of STP effluent in Arcata Bay from three plants in the Humboldt Bay area as affected by the physical characteristics of the Arcata Bay basin, the tidal cycle and intensity of tidal height fluctuation, and the physical characteristics of the different water masses in the bay,

2) to determine the dilution ratios of effluent to bay water as it spread from the STP's,

3) to determine the time of travel of effluent from the STP's to important commercial and sport shellfish harvesting areas.

Rhodamine-WT® dye was injected into the three STP outfalls on three days in April of 1979, then observed from fixed-wing aircraft and boats. The boats were equipped with fluorometers to measure the actual concentration of the dyed effluent. Air-to-boat, boat-to-boat, and boat-to-land communications integrated the effort by synchronizing all field personnel.

The results of the study are presented primarily in graphs and maps for ease in expression. They are then discussed in terms of the threat to sport and commercial harvest of shellfish. The data of previous studies are referred to in clarification of points and comparison of results. Suggestions for further study are also presented.

METHODS

Dye Adjustments and Injections

Aqueous Rhodamine-WT® obtained from du Pont de Nemours and Company was used as the fluorescent tracer. The density was adjusted with methanol by equal volume dilution to 0.972 ± 0.025 specific gravity. The resultant solution was then injected into the STP discharge line using a Masterflex R variable speed peristaltic pump. The dye solution delivery rates were checked periodically during the injection periods. STP flow rates were monitored during the injection periods, then instantaneous dilution rates and dye concentrations for the outfall were calculated.

Dye concentrations were expressed in parts per billion (ppb) active ingredient on a weight-to-weight basis as per Furfari (1978). Basically, the method of calculation involved assuming the Rhodamine-WT solution as received from du Pont to be 20% dry dye by weight with a specific gravity of 1.2. With those factors, the assumed weight of dry Rhodamine-WT (active ingredient) in any volume of Rhodamine-WT solution could be calculated as follows:

Kg dry Rhodamine-WT = L. solution X 0.20 X 1.2.

Although a criticism of that method is contained in an appendix to this report, all dye concentrations appear as ppb on the weight-to-weight basis as calculated above.

Sampling Equipment

In situ measurements were accomplished with three boats each equipped with fluorometers and attending equipment. The boats were also linked by citizens band communications to one another and the ground crew at the dye injection point. The command boat was also in communication with a fixed-wing aircraft via radio. Thus, messages concerning dye cloud position, tidal shear lines, and navigational hazards could be communicated from the aircraft to all of the field personnel.

Three Turner Designs ® model 10-005R field fluorometers were used for dye detection and dye concentration measurements. All instruments were calibrated at the same sensitivity with a standard dye solution in bay water. Background fluorescence was "blanked out" or set to zero fluorescence. The consistency of the three instruments was checked periodically during the study.

The fluorometers were fitted with flow-through cuvettes, allowing for rapid in situ sampling. The light and filter combinations used were as follows: Lamp - 10-046 clear quartz, Excitation filter = color specification (c.s.) 546, Reference filter = c.s. 16, Emission filters = c.s. 23A and c.s. 4-97.

Sample collection was accomplished with 12-volt DC submersible pumps. Flexible opaque tubing allowed for sample collection from various depths. Tubing length on the pump side of the fluorometer was kept to a minimum to ensure rapid sample delivery to the instrument and rapid flushing of the tubing. The exit flow tubing was kept away from the sampling pump.

All fluorometers were linked to galvanometric recorders. Two of the recorders marked instrument sensitivity setting as well as fluorescence; the third required hand-written notes for sensitivity settings. Recorder tapes were marked with time, date, and location of each sample transect. Pertinent notes were recorded at each sampling location to aid in data interpretation.

The in situ dye concentrations were not temperature corrected since the averaging of the peaks and troughs on the recorder tapes were ± 5% of the full scale. That precision bracketed any expected fluorescence differences attributable to changes in temperature of the bay water.

Tide Gauge

A Stevens ® type F stage recorder was installed over a wood-frame stilling well for tidal height measurements in the study area. The gauge was located at the California Department of Fish and Game "J" Street dock in Eureka on the Eureka Inner Reach. Tidal heights were adjusted to the datum for the predicted tidal heights for the period of study from the published data of the National Oceanic and Atmospheric Administration (NOAA).

Since it was impractical to set the stage recorder at the same datum used for the NOAA heights, a factor was calculated to adjust the recorder heights to the NOAA datum. This involved setting an arbitrary "0" point on the recorder chart, then recording the observed heights from that point during the study period. The differences between the observed high and low tide heights and the NOAA high and low tide heights were averaged. That average difference (-3.73 feet) was then subtracted from the observed tidal height, adjusting it to the NOAA datum. For example: The observed higher low tide on April 24 was -3.75 feet; the NOAA prediction was 0.3 feet. Subtracting the average difference of -3.73 feet from the observed height resulted in an adjusted height of -0.02 feet.

Injection Sequences

The dye injections were performed during those daylight-hour tidal cycles in which it was thought the most effect to the Arcata Bay would be evident. The injections were scheduled as follows:

1) Hill Street STP - April 24, 1979:
   1030 - lower high tide
   1120 - ebb beginning, dye injection started
   1600 - higher low tide
   1640 - dye injection ended

2) Arcata STP - April 25, 1979:
   1130 - lower high tide
   1255 - ebb beginning, dye injection started
   1630 - dye injection ended
   1645 - higher low tide

3) Murray Street STP - April 26, 1979:
   0615 - lower low tide
   0715 - dye injection started
   0840 - dye injection rate doubled
   1040 - dye injection ended
   1215 - lower high tide.

The injection times are shown as darkened bands on the tidal height plot in Figure 1.

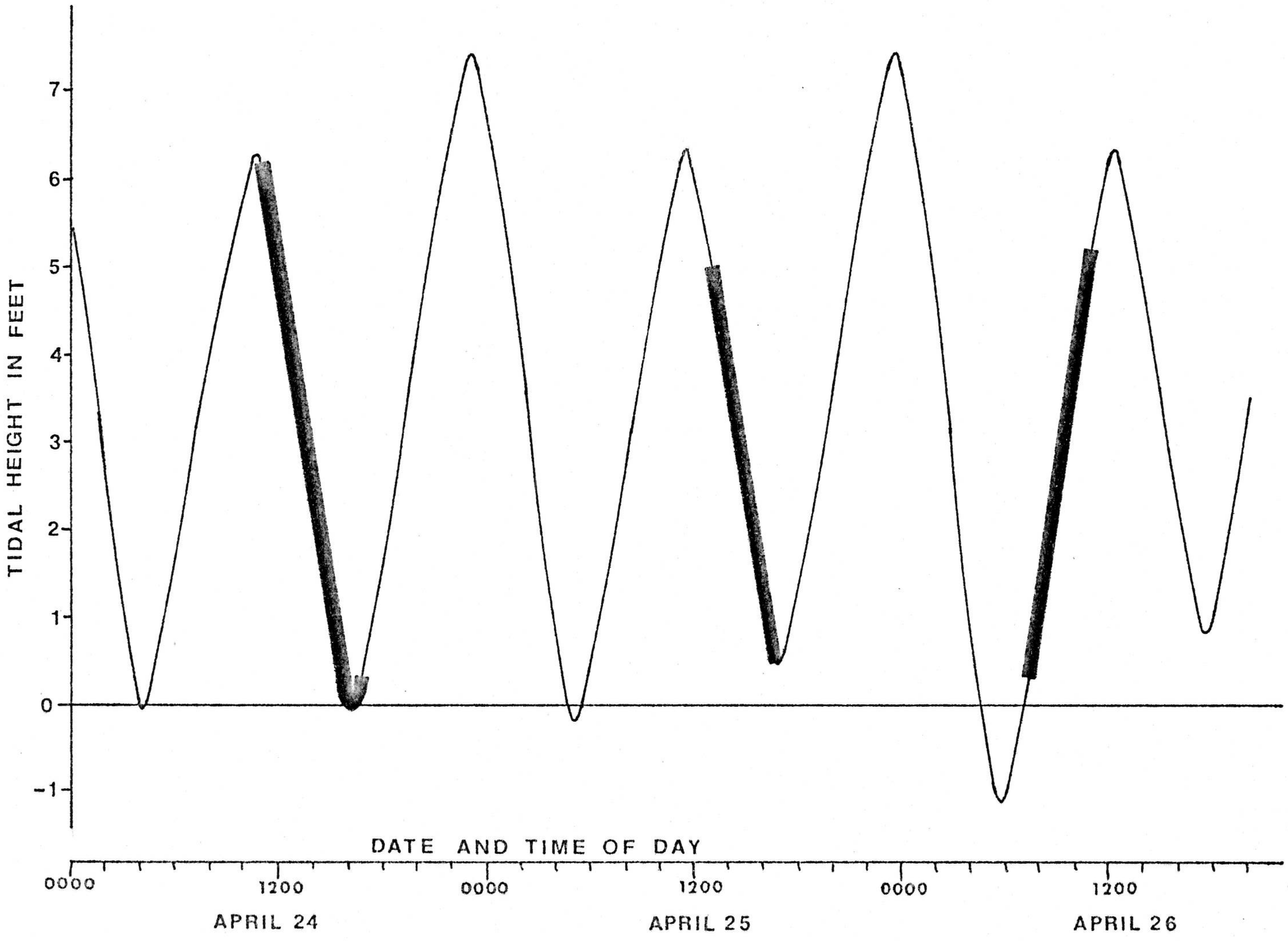
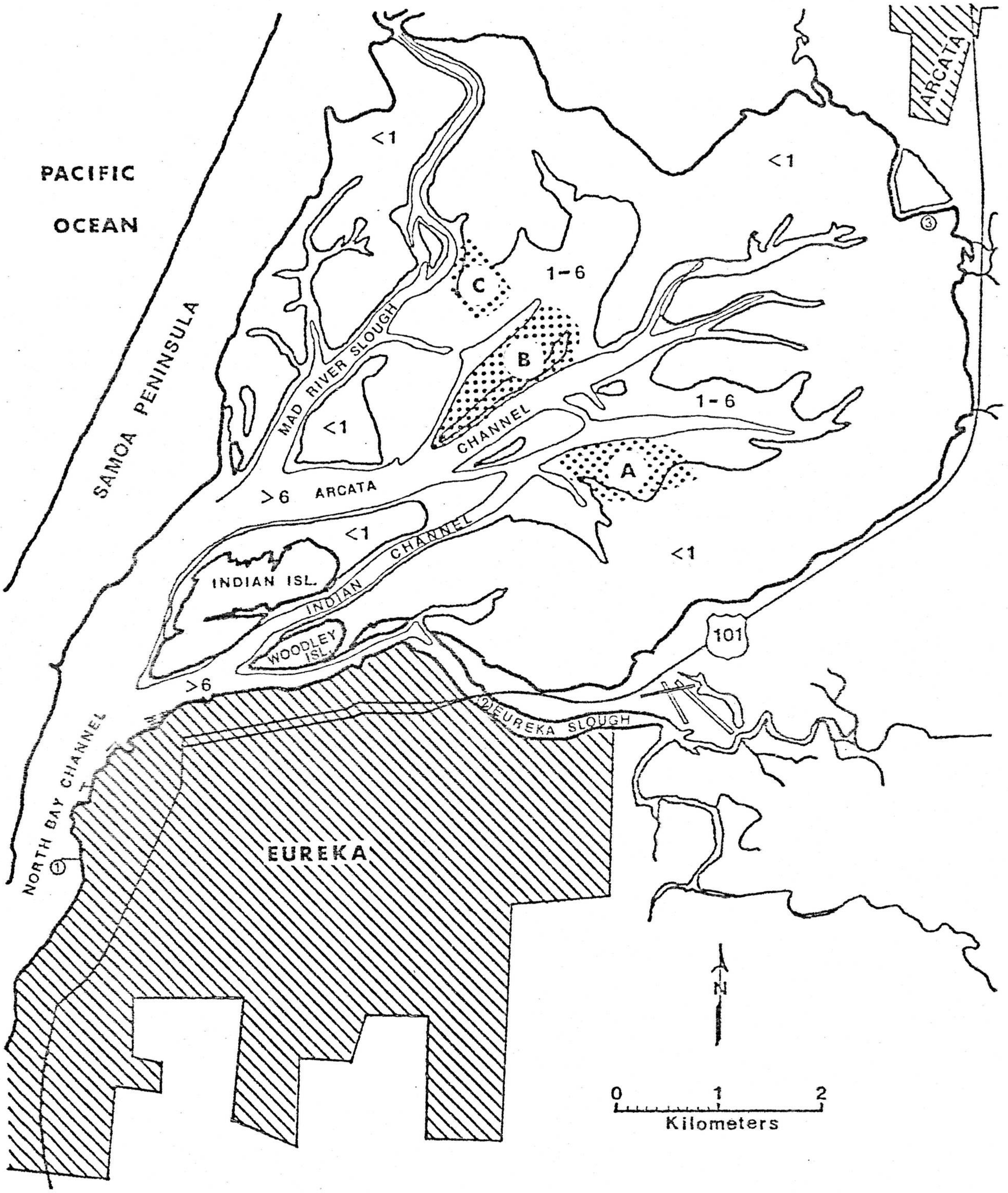


Figure 1. Tidal heights as measured at the "J" Street dock during the dye injection periods for Hill Street, Arcata, and Murray Street STP's in April of 1979. (Heavy lines denote the dye injection periods for each study, respectively)

Navigation

Standard U.S. Coast and Geodetic Survey charts of Humboldt Bay (scale = 1:25,000) were used for navigation. Grids of 0.25 nautical miles (500 yards) were drawn on the maps and labeled with letters on one axis and numbers on the other. This system allowed easier communication and charting of the dye cloud movements. The oyster culture areas delineated by "ray fences" were given letter designations to simplify descriptions of dye cloud movements. They were as follows: A) Southern Arcata Bay near the Brainard mill, B) adjoining the Arcata Channel in Arcata Bay, and C) adjoining the Mad River Slough north of beds "B" (Figure 2).



PACIFIC OCEAN
SAMOA PENINSULA
ARCATA
<1
<1
1-6
C
B
MAD RIVER SLOUGH
<1
1-6
A
CHANNEL
>6 ARCATA
<1
CHANNEL
INDIAN ISL.
INDIAN
<1
WOODLEY ISL.
101
>6
NORTH BAY CHANNEL
①
②
EUREKA SLOUGH
③
EUREKA
N
0
1
2
Kilometers

Figure 2. The locations of the three sewage treatment plant discharges studied in April of 1979 and the commercial oyster culture areas in Arcata Bay. (① = Murray Street STP, ② = Hill Street STP, ③ = Arcata STP; stipled areas denote oyster culture areas; depth curves are in feet, datum is mean lower low water)

RESULTS

Dye tracer work during this study further reinforced previous work. It pointed out that effluent from any of the three sewage treatment plants would be found in the oyster culture areas within one full tidal cycle.

Dyed effluent from the Hill Street STP moved down the channels during the ebb tide, but reversed on the flood tide, moving over oyster culture area "A". That tidal flood of dyed effluent occurred within two and a half hours of flood tide (tidal rise of 2.8 feet).

Dyed effluent from the Arcata STP traveled to the eastern tip of oyster culture area "B" within one tidal ebb (tidal drop 5.95 feet). That dyed effluent was still measurable the following day, two tidal flood cycles later.

Dyed effluent from the Murray Street STP traveled from the plant up all three north bay channels into Arcata Bay within one tidal flood of 7.5 feet. Dyed effluent from that release was detected within oyster culture areas "A" and "B" at slack high tide.

Two days following the last addition of dye to the bay, dye was detected throughout Arcata Bay, indicating that effluent from the three plants is present in Arcata Bay at any one point in time.

The results of each of the three dye releases are dealth with individually in this section. The total picture is then presented in detail in the discussion section as an integration of all the results.

Hill Street STP

The dye injection was started on April 24, at 1120, 50 minutes after the lower high tide, at the beginning of visible tidal ebb within Eureka Slough. The STP flow rate was 750 gallons per minute (gpm) throughout the study. Observed tide heights and times were: 6.28 feet at 1030, -0.02 feet at 1615, and 7.43 feet at 2300.

The dye cloud moved down Eureka Slough as a narrow band, winding back and forth across the channel. The leading edge of the dyed effluent reached the railroad bridge 27 minutes after release (350 yd., 13 yd/min). The cloud hugged the west shore of Eureka Slough about 200 yards from the release point until reaching the confluence with Daby Slough.

At the confluence of Eureka Slough and Daby Slough (50 minutes after injection, 950 yds., 19 yds/min velocity) the cloud formed a very distinct band, staying within the Eureka Slough water mass on the south side of the Eureka Inner Reach (Figure 3). Although no temperature-salinity casts were made along the line separating Daby and Eureka Sloughs, fluorometric data showed the dyed mass of water was at five feet depth ten feet from the line. In other words, the dyed mass was under the lighter (probably slightly warmer) water from Daby Slough (originating on the mud flats). By the time the cloud had reached the Eureka boat basin, it filled the entire width of the Eureka Inner Reach. At that point, it was probable that Daby and Eureka Slough waters were completely mixed. The "boundary" effect at the confluence of the sloughs diminished further into the tidal ebb, probably as density differences between the two water masses lessened.

Although it is unknown when the leading edge of the dyed effluent reached its farthest point, the detectable limit was encountered at the Murray Street STP outfall site at 1408 (168 min., 5700 yds., 34 yd/min). That travel was accomplished within 2.08 feet of tidal ebb drop, representing 2740 yards of travel per foot of tidal ebb.

As the dye cloud stabilized in concentration with continued dye injection, it occupied more of the Eureka Slough and Eureka Inner Reach, filling both channels bank to bank. The detectable edge of the stabilized cloud remained at the Murray Street outfall, that being the end of measurable dye fluorescence. By using an average outfall dye concentration during that steady state period of 3000 ppb and the concentrations of dye at various points in the bay during the period, dilution ratios of effluent to bay water were estimated (Figure 4). At the Humboldt Seafoods Dock (4360 yards from the STP) at 1411 the dilution ratio was 1:7500. The dilution ratio at the railroad bridge (330 yards from the STP) at 1505 was 1:300.

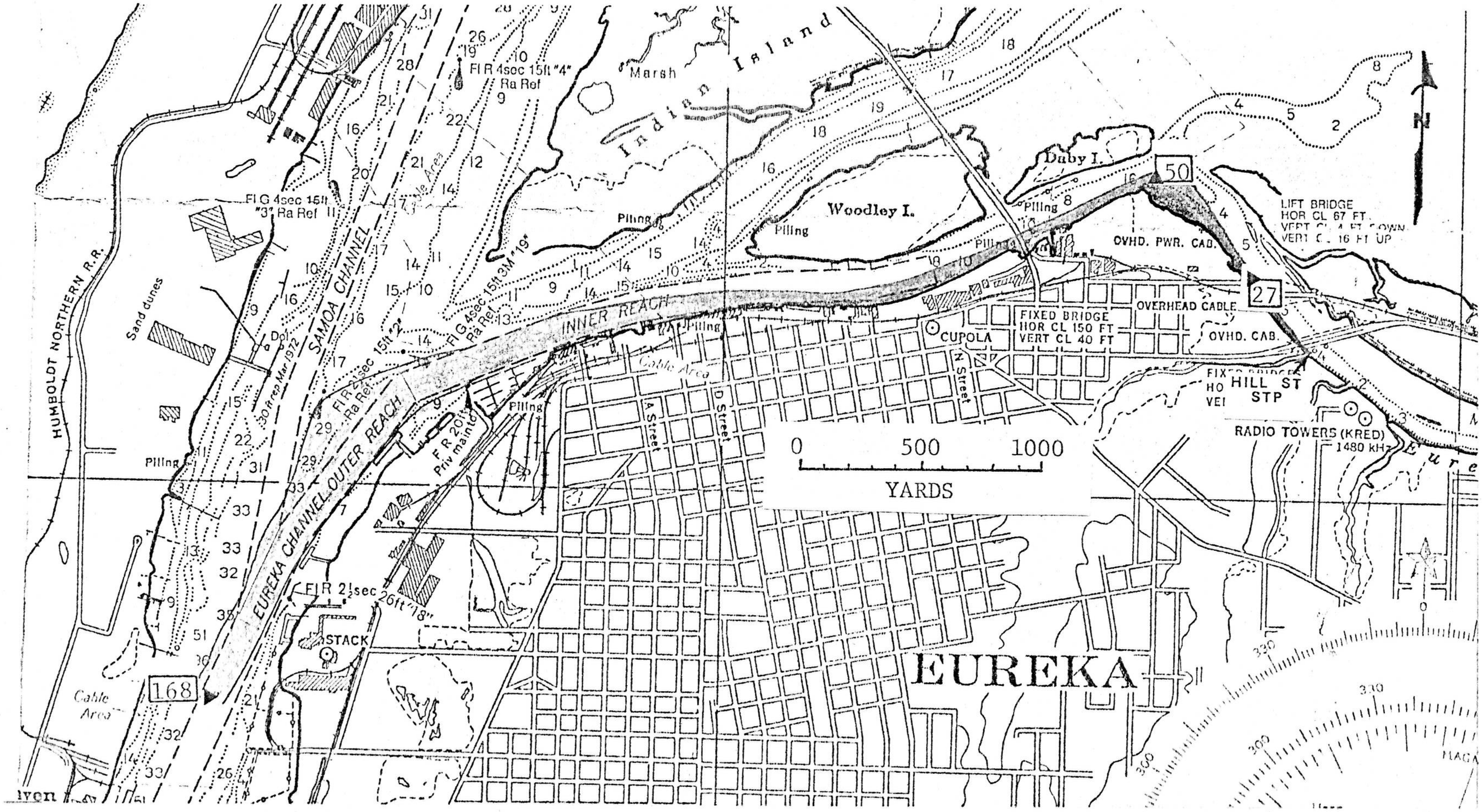

N
Indian Island
Marsh
Woodley I.
Duby I.
LIFT BRIDGE
HOR CL 67 FT
VERT CL 16 FT UP
50
27
168
OVHD. PWR. CAB.
OVERHEAD CABLE
OVHD. CAB.
FIXED BRIDGE
HOR CL 150 FT
VERT CL 40 FT
CUPOLA
N Street
D Street
A Street
HILL ST
STP
RADIO TOWERS (KRED)
1480 kHz
INNER REACH
EUREKA CHANNEL OUTER REACH
SAMOA CHANNEL
Sand dunes
HUMBOLDT NORTHERN R.R.
Piling
Cable Area
STACK
EUREKA
0
500
1000
YARDS

Figure 3. The configuration and extent of the Hill Street STP dyed effluent mass during the April 24, 1979, short-term dye injection study. Times of dyed mass detection are given in minutes from initiation of injection. Depth contours are in feet, datum is mean lower low water.

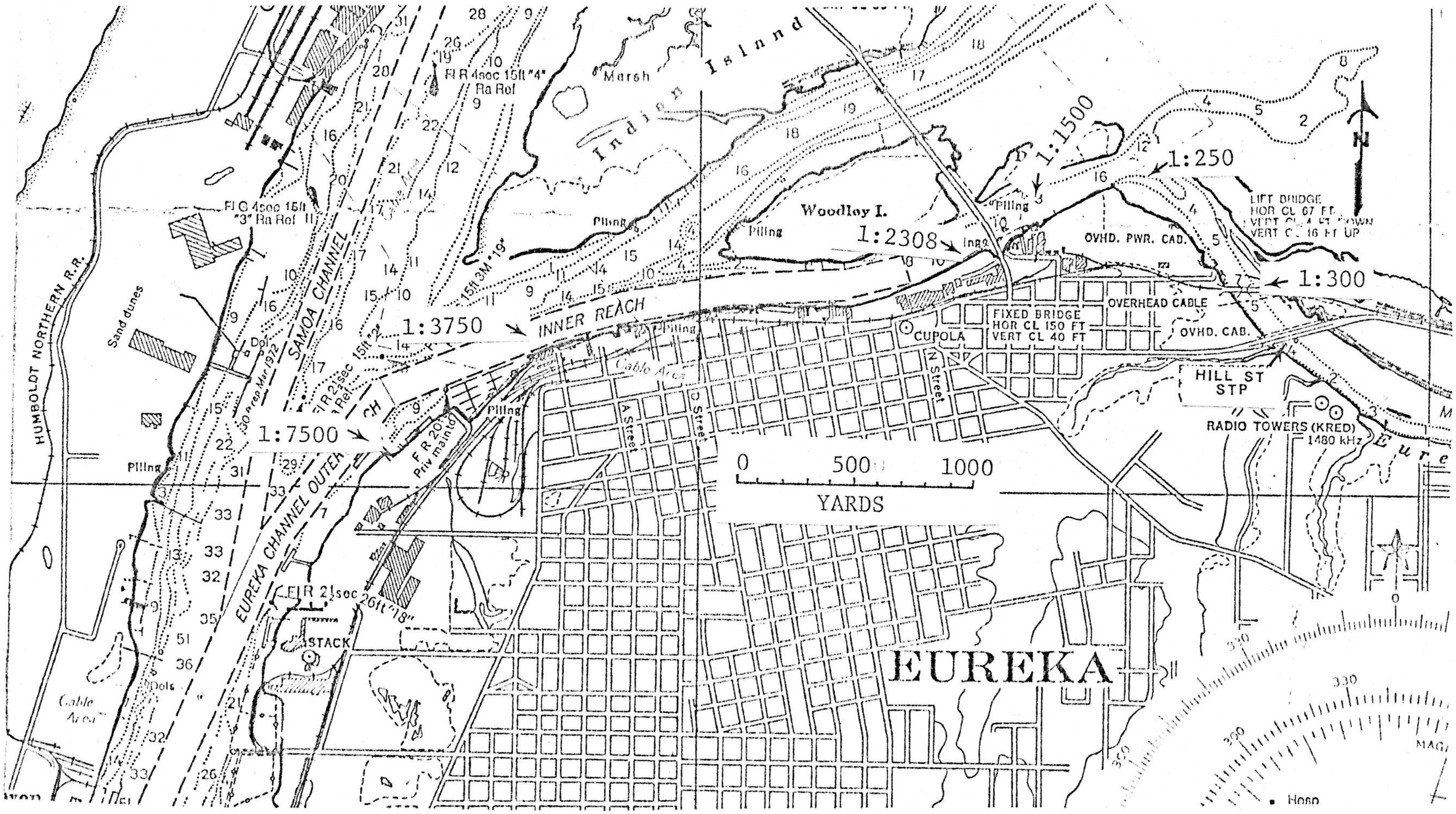

1:250
1:300
1:1500
1:2308
1:3750
1:7500
LIFT BRIDGE
HOR CL 67 FT
VERT CL 4 FT DOWN
VERT CL 16 FT UP
N
OVHD. PWR. CAB.
OVERHEAD CABLE
OVHD. CAB.
FIXED BRIDGE
HOR CL 150 FT
VERT CL 40 FT
CUPOLA
HILL ST
STP
RADIO TOWERS (KRED)
1480 kHz
Woodley I.
Indian Island
Marsh
Piling
INNER REACH
SAMOA CHANNEL
EUREKA CHANNEL OUTER
Cable Area
N Street
A Street
D Street
0
500
1000
YARDS
EUREKA
STACK
Sand dunes
HUMBOLDT NORTHERN R.R.
Fl R 4sec 15ft "4" Ra Ref
Fl G 4sec 15ft "3" Ra Ref
F R 20ft Priv maintd
Fl R 2½sec 26ft "18"
MAG

Figure 4. Effluent to bay water dilution ratios during the April 24, 1979, short-term dye injection study. Depth contours are in feet, datum is mean lower low water.

The plot of dye concentration versus distance from the STP during steady state conditions illustrates the dilution of effluent, and transport of the mass down channel (Figure 5). The majority of the dilution was accomplished in the first 1500 yards (nominally 45 minutes into ebb tide). The remaining 4200 yards was seen as minimal dilution, mainly transport of diluted effluent.

A synopsis of the plant flow, dye use, and outfall dye concentration appears as Figure 6. As can be seen from that figure, outfall dye concentration was a function of dye injection rate, the plant flow remaining constant throughout the period. Six grab samples acquired from the outfall boil represent the initial dilution of the dyed effluent, the rate of dilution decreasing (concentration increasing) with time through the ebbing tide.

Within 110 minutes of slacklow tide (slacklow tide @ 1600) dyed water was detected 1500 yards east of Samoa Bridge in the Indian Channel (Figure 7). The flood tide movement represented about 2500 yards of travel from the confluence of Indian Channel with Eureka Inner Reach (23 yds/min. velocity).

The tide turned somewhat later at the Eureka-Daby Slough confluence, moving dyed water from that intersect to the eastern end of Daby Slough by 1740 (100 min. after slack low) (Figure 7). Navigation was impossible beyond that point, however, the dyed mass undoubtedly moved easterly across the mud flats.

Dyed effluent was detected within oyster culture area "A" at 1830 (150 min. after slack low tide), however, it is unknown if the dye was from the Indian Channel or Daby Slough. The movement to the oyster culture area occurred within 2.8 feet of tidal flood, slightly less than one-third of the tidal period rise of 7.45 feet in 420 minutes.

Arcata STP

The release of dye was started at 1255 on April 25, 85 minutes after the lower high tide when flow from the STP discharge pipe through the tide gate to the bay had begun. Plant flow during the release varied from 1175 to 1632 gpm. Observed tide heights ("J" Street gauge) were: 6.38 feet @ 1130, 0.43 feet at 1645.

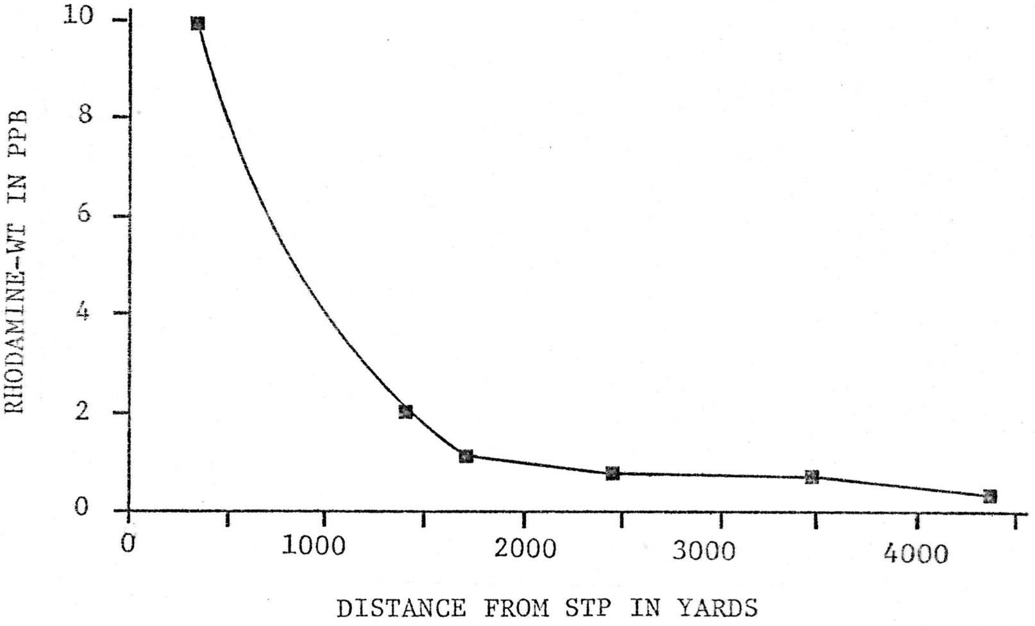


Figure 5. Concentration of Rhodamine-WT versus distance from the Hill Street STP during the April 24, 1979, short-term dye injection study.

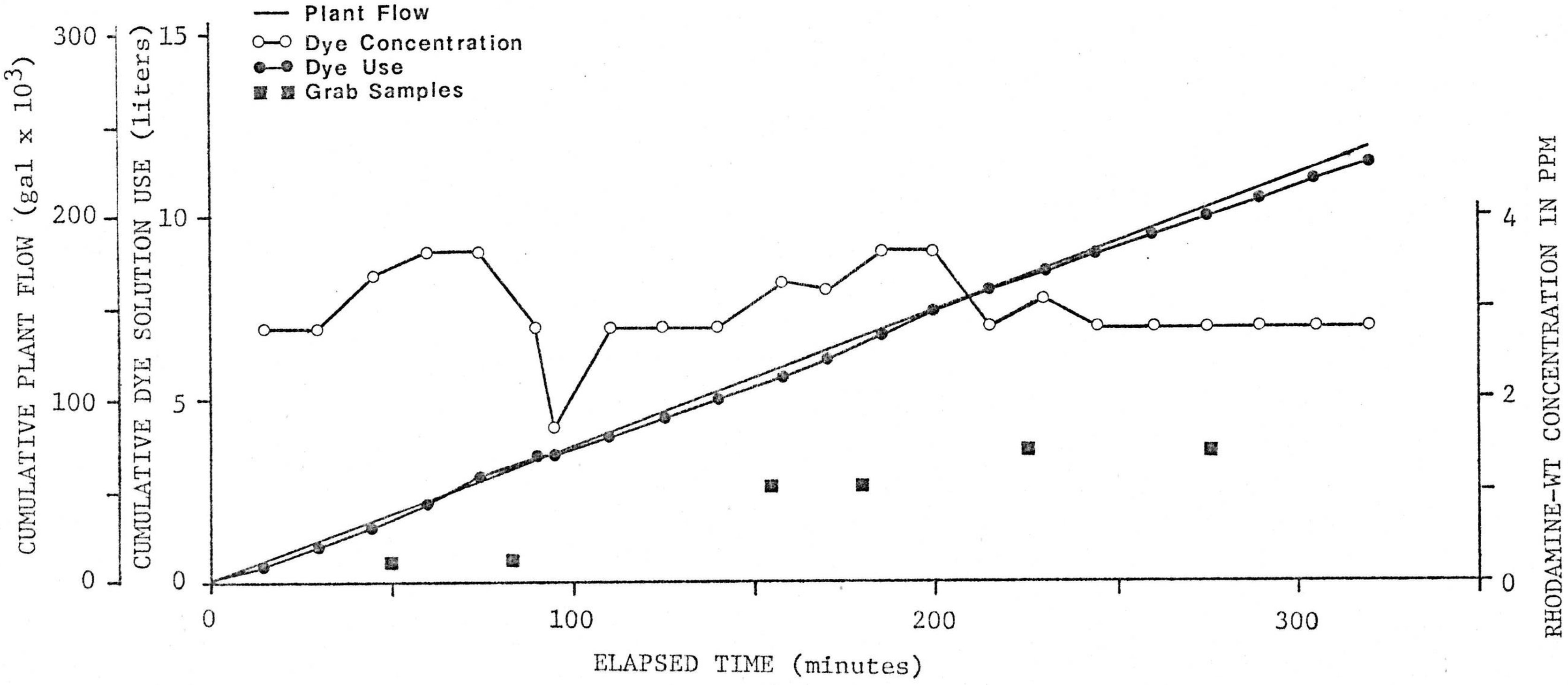


Figure 6. Synopsis of cumulative plant flow, cumulative dye use, and dye concentration at the Hill Street STP outfall during the April 24, 1979, short-term dye injection study. Grab samples were from the outfall boil and represent initial dilution at the boil.

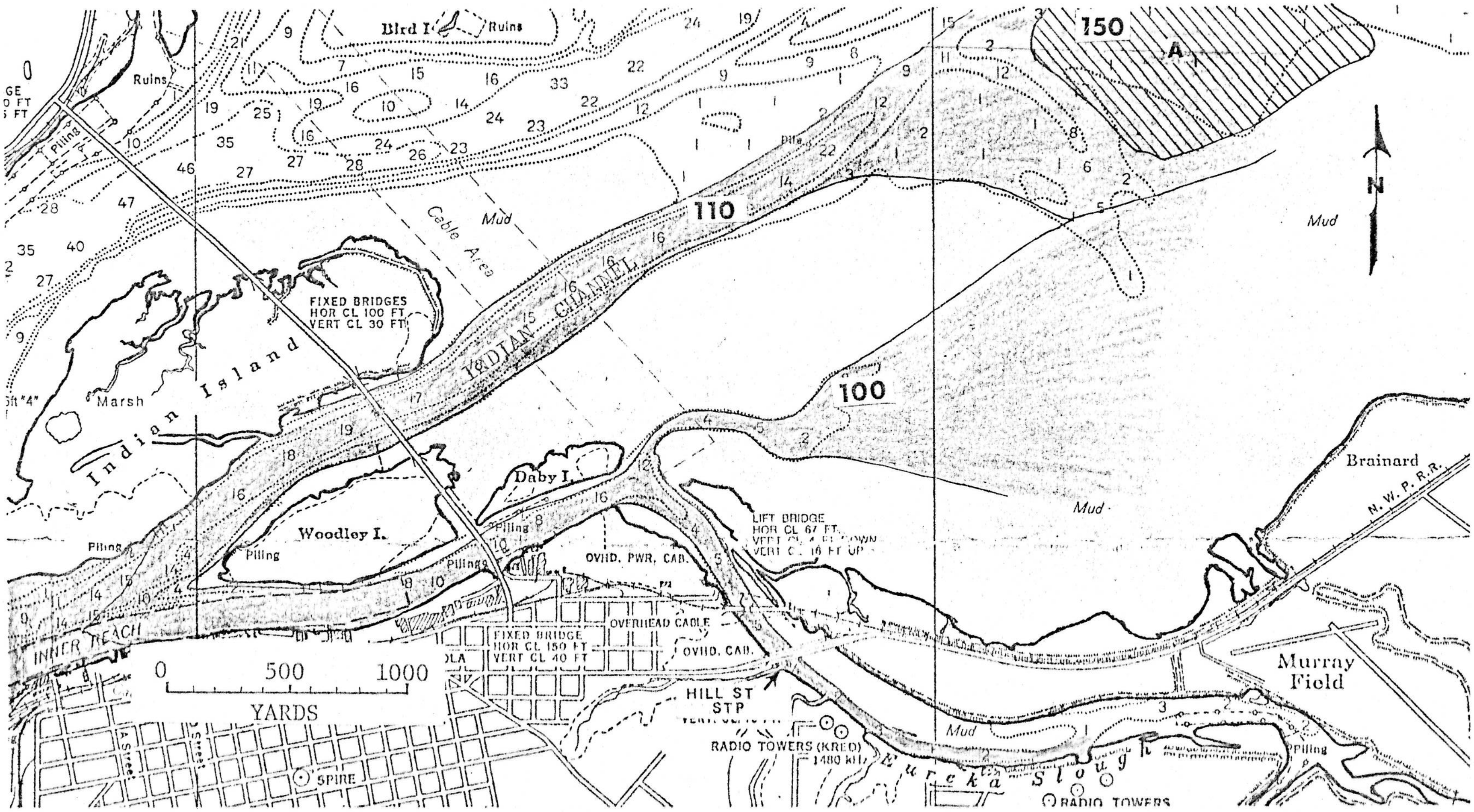

150
A
110
100
N
Mud
Bird I.
Ruins
Cable Area
INDIAN CHANNEL
FIXED BRIDGES
HOR CL 100 FT
VERT CL 30 FT
Indian Island
Marsh
Daby I.
Woodley I.
Piling
OVHD. PWR. CAB.
OVERHEAD CABLE
FIXED BRIDGE
HOR CL 150 FT
VERT CL 40 FT
LIFT BRIDGE
HOR CL 67 FT
OVHD. CAB.
HILL ST
STP
RADIO TOWERS (KRED)
1480 KHz
Eureka Slough
RADIO TOWERS
Murray Field
Brainard
N. W. P. R.R.
INNER REACH
SPIRE
0
500
1000
YARDS

Figure 7. Locations and elapsed times of detectable dyed water masses during flood tide from the Hill Street STP short-term ebb tide dye injection study, April 24, 1979. Times are in minutes from slack low tide. Depth contours are in feet, datum is mean lower low water. Oyster culture areas are designated by diagonal-lined enclosure.

The dye initially moved as a band in a southerly direction until water from the extensive mud flats to the east began to drain into the tideways. At that time, the dyed water mass split into the two Arcata channels ("Ramp" and "STP) and the Jacoby Creek channels. The majority of the cloud moved down the Arcata STP and North Jacoby channels (Figure 8).

The dyed water mass moving down the Arcata channel reached the eastern end of oyster culture area "B" by 1705 (slack low tide), four hours and ten minutes after the start of injection. The total tidal fluctuation was estimated at 5.95 feet during that period. The movement of dyed water from the STP to the oyster culture area represented 4100 yards of travel in 250 minutes of tidal ebb, an average of 726 yds/feet tidal drop and an average velocity of 16.4 yards per minute. Subtracting out the time that the dyed mass remained on the mud flats, the average velocity within the Arcata channel was 28.9 yards per minute.

Dye movement down the North Jacoby channel reached the confluence of the two Jacoby channels by 1520, two hours and 25 minutes after release (Figure 8). That mass of water then merged with the mass from the Arcata channel at 1629, representing a 4000 yard movement down the Jacoby channels at an average velocity of 18.7 yards per minute.

Three hours and 50 minutes from dye injection, dyed water was detected in "Shark Alley" (Figure 8). Aerial observations showed that a small arm of the dyed mass split from that entering the Jacoby South channel and moved into Shark Alley.

When steady state conditions were achieved in the release period, dye concentration measurements were made to determine dilution ratios. The plot of dye concentration versus distance from the STP during the steady state period illustrates the dilution of the effluent with transport down the Arcata and Jacoby Creek channels (Figure 9). The majority of the dilution was accomplished in the Arcata channel at the confluence of the "Ramp" and "STP" channels (1900 yards from the STP). The majority of the dilution in the Jacoby North channel occurred prior to the confluence with Jacoby South channel (2400 yards from the STP).

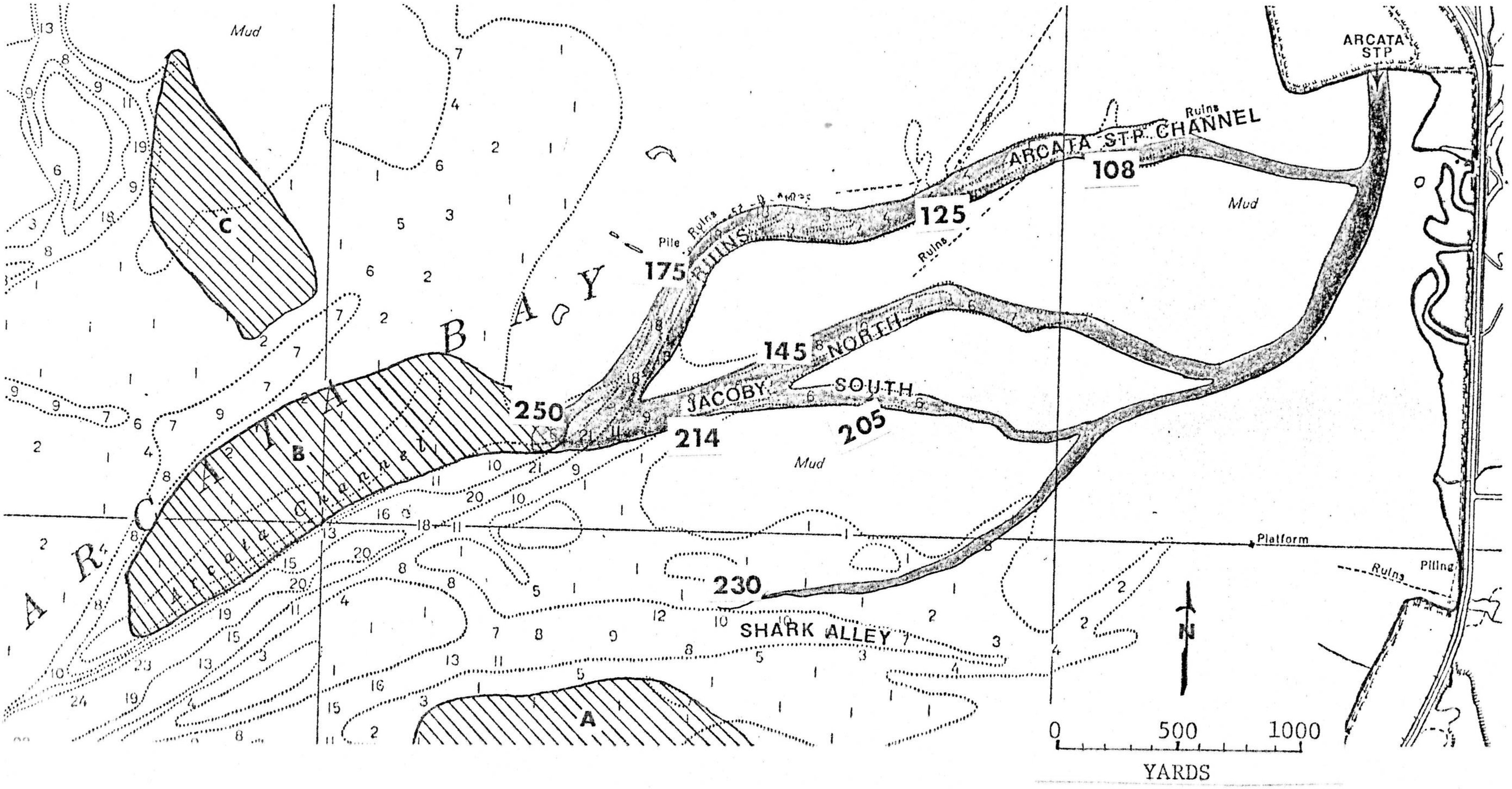

Mud
C
ARCATA STP
ARCATA STP CHANNEL
Ruins
108
125
Mud
175
Pile
RUINS
145
NORTH
SOUTH
JACOBY
205
250
214
Mud
B
A
Y
ARCATA
Arcata Channel
B
230
SHARK ALLEY
Platform
Piling
Ruins
N
A
0
500
1000
YARDS

Figure 8. Configuration and extent of the Arcata STP dyed effluent mass during the April 25, 1979, short-term dye injection study. Times of dyed mass detection are given in minutes from initiation of injection. Depth contours are in feet, datum is mean lower low water. Oyster culture areas are designated by diagonal-lined enclosures.

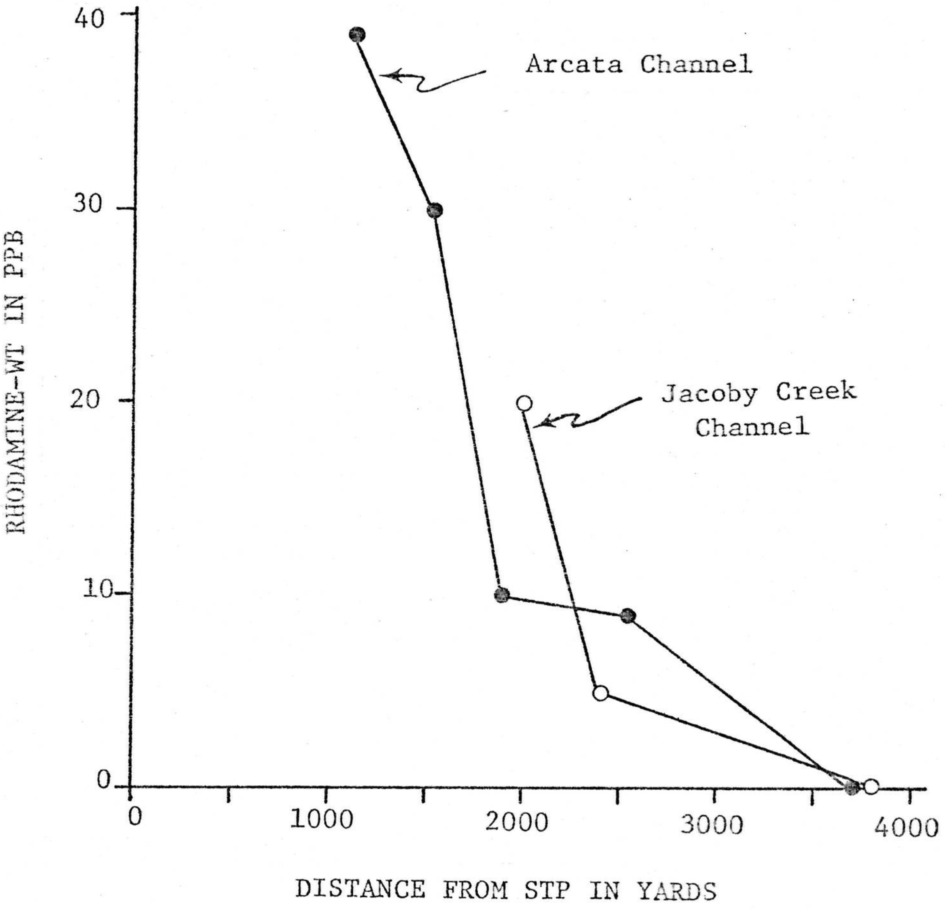


Figure 9. Concentration of Rhodamine-WT versus distance from Arcata STP in Arcata and Jacoby Creek channels during the April 25, 1979, short-term dye injection study.

By using the average outfall concentration of 2100 ppb dye, dilution ratios were calculated. The dilution ratio at the eastern end of the oyster culture area "B" was 1:35,000, whereas in Shark Alley near oyster culture area "A" was 1:52,000 (Figure 10).

A synopsis of the plant flow, dye use, and calculated outfall dye concentrations appears as Figure 11. Variations in calculated dye concentrations arose from variations in both plant flow rate and dye injection rates.

Dyed water was detected the following day, in both the Jacoby Creek and Arcata channels, two flood cycles after the injection ended. The concentrations of dye ranged from 0.07 to 3.0 ppb, the larger concentrations found nearer the STP (Figure 12).

Murray Street STP

Dye injection was begun at 0715 on April 26, 1979, one and a half hours after the lower low tide, when tidal flood was evident at the outfall. Plant flow averaged 2607 gpm, ranging from 1910 to 2847 gpm. Observed tide heights and times were: -1.12 feet at 0545, 6.38 feet at 1215.

The dyed water mass remained in the eastern one-third of the Eureka channel until approaching the Humboldt Seafoods docks, where it began to spread out. The leading edge of the dyed mass reached the confluence of the Samoa and Eureka channels at 0755, 40 minutes after initial injection. The cloud then moved up both channels (Figure 13).

The dyed mass moving up the Samoa channel reached Samoa Bridge by 0930. A small arm split from the main body and moved into Mad River Slough, reaching the Manila-Mad River Slough confluence before it became undetectable. The main body of dyed water travelled to the western end of oyster culture area "B" by 1115, four hours after release (Figure 13). Although dye from the previous day's Arcata STP injection was apparent up the channel near the "ruins", a clear separation from the Murray Street STP dye mass was maintained. That movement of dyed water from the Murray Street STP to the edge of oyster culture area "B" represented a travel of 6914 yards in 240 minutes, an average velocity of 28.8 yards per minute, and 1411 yards of

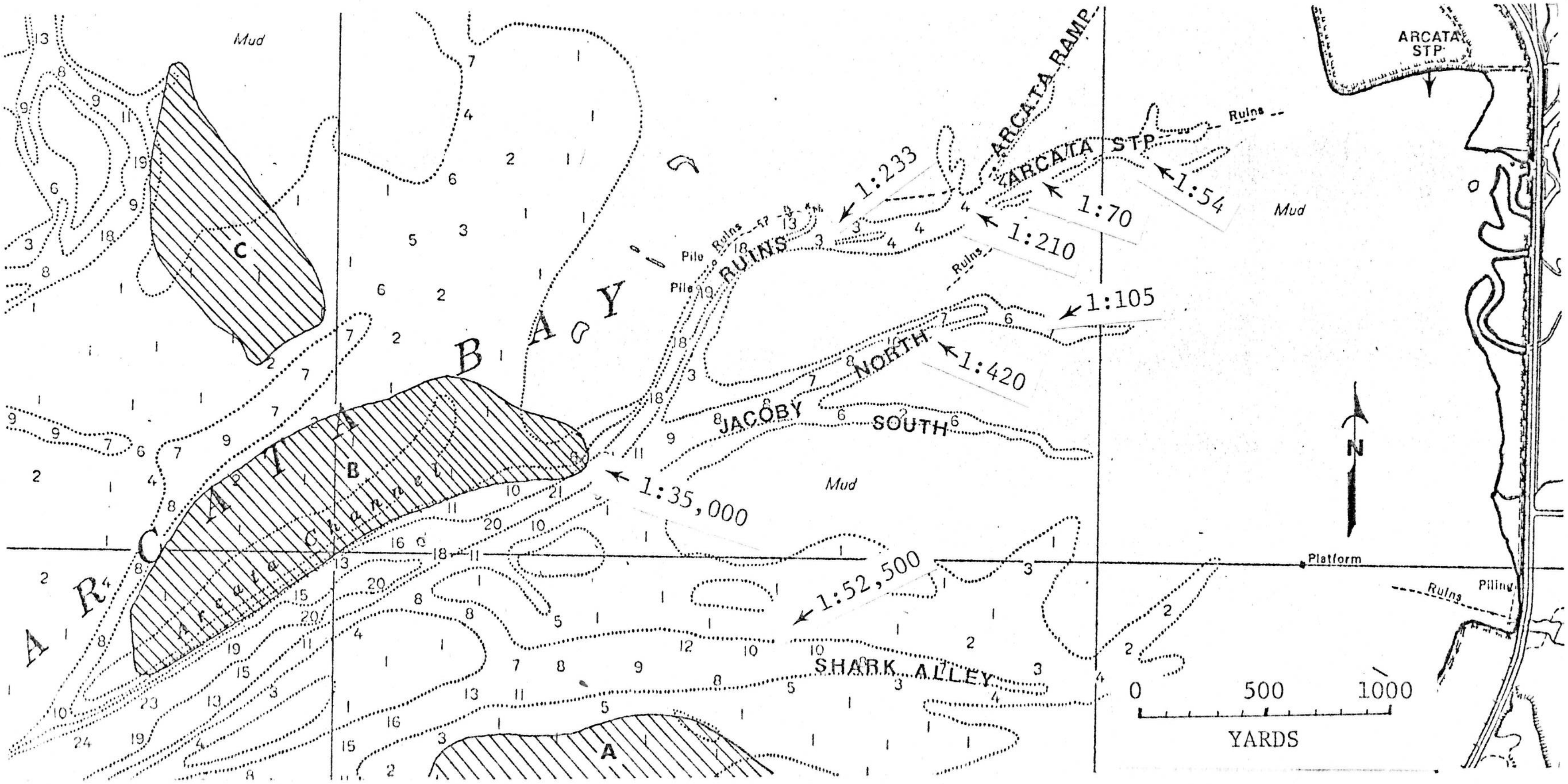

Mud
ARCATA STP
Ruins
ARCATA RAMP
ARCATA STP
1:233
1:54
1:70
1:210
1:105
1:420
RUINS
Pile
NORTH
JACOBY
SOUTH
BAY
ARCATA
Arcata Channel
C
B
A
1:35,000
1:52,500
Mud
SHARK ALLEY
N
Platform
Piling
0
500
1000
YARDS

Figure 10. Effluent to bay water dilution ratios during the April 25, 1979, Arcata STP short-term dye injection study. Depth contours are in feet, datum is mean lower low water. Oyster culture areas are designated by diagonal-lined enclosures.

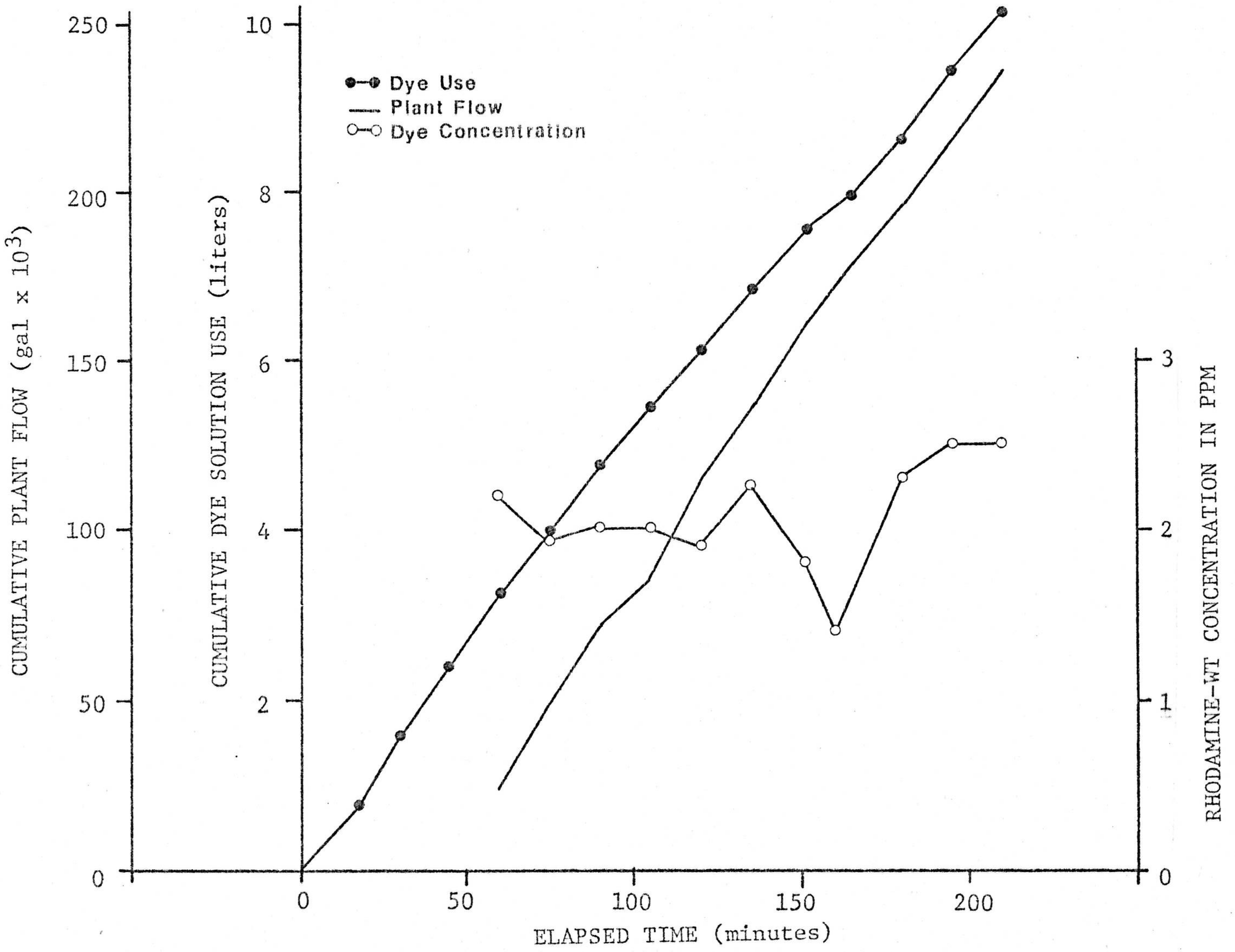


Figure 11. A synopsis of cumulative plant flow, cumulative dye use, and dye concentration at the Arcata STP outfall during the April 25, 1979, short-term dye injection study.

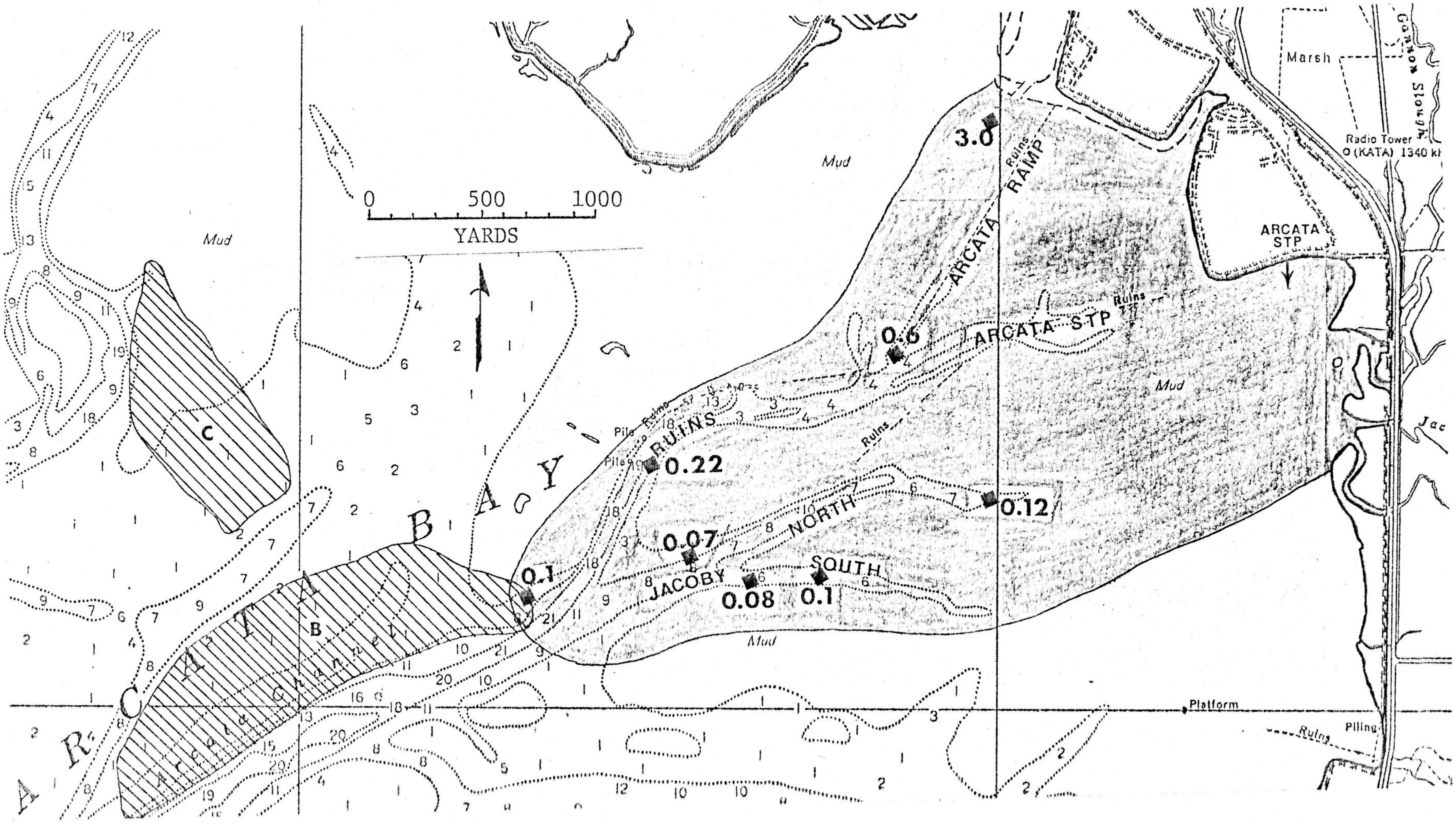
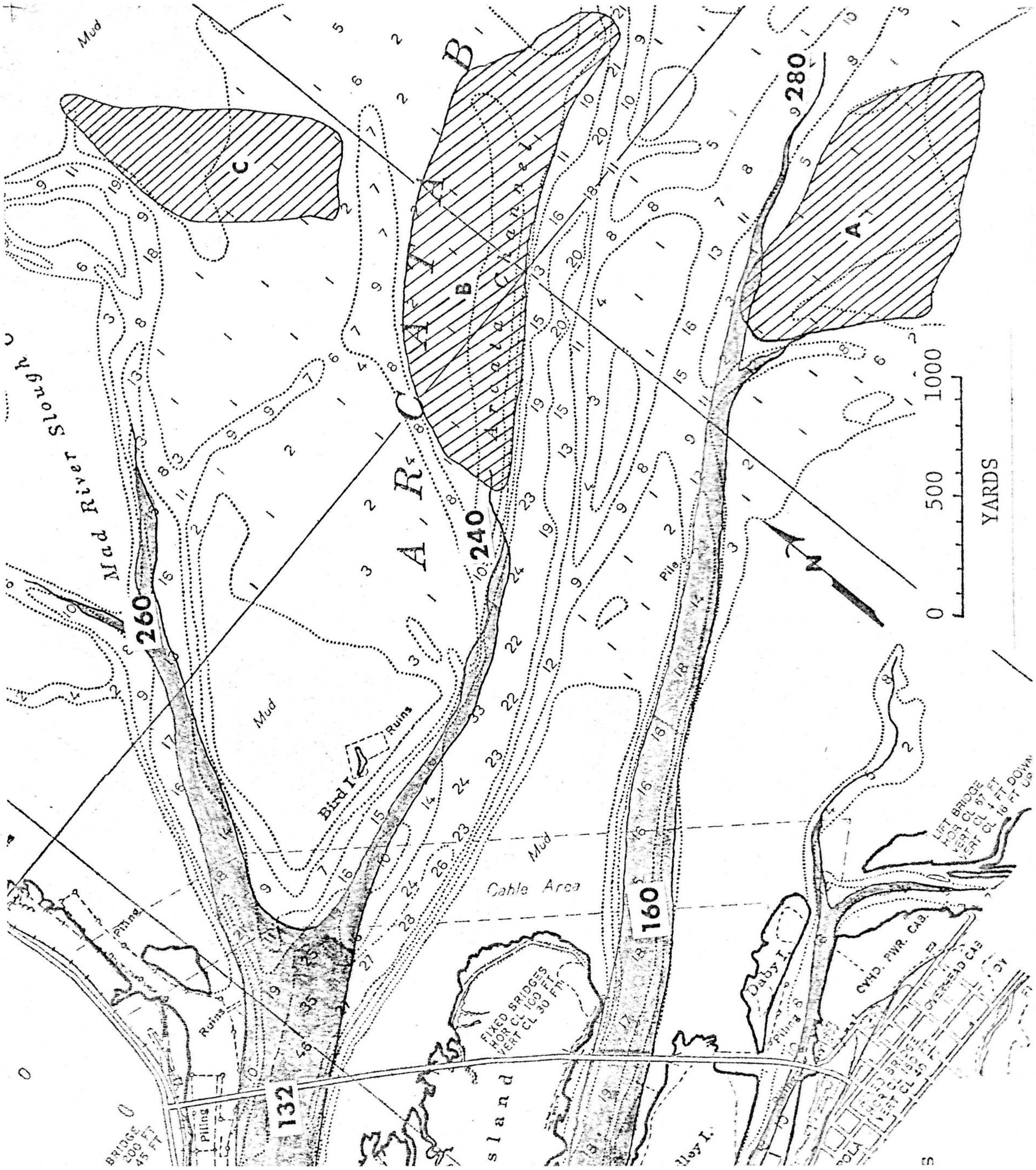

Gannon Slough
Marsh
Radio Tower
O (KATA) 1340 kH
ARCATA STP
ARCATA RAMP
Ruins
ARCATA STP
Mud
3.0
0.6
0.12
0.22
0.07
0.08
0.1
0.1
RUINS
NORTH
SOUTH
JACOBY
Pile
Platform
Piling
Jac
0
500
1000
YARDS
Mud
C
B
ARCATA BAY
Arcata Channel

Figure 12. The extent of and dye concentrations of the dyed water mass during the lower high tide on April 26, 1979, originating from the Arcata STP April 25, 1979, short-term dye injection study. Two tidal flood cycles occurred between injection and this data collection. Concentrations are in parts per billion Rhodamine-WT. Depth contours are in feet, datum is mean lower low water. Oyster culture areas are designated by diagonal-lined enclosures.


A
B
C
132
160
240
260
280
0
500
1000
YARDS
N
Mad River Slough
Mud
Arcata Channel
Cable Area
Bird I.
Ruins
Piling
Daby I.
FIXED BRIDGES HOR CL 160 FT VERT CL 30 FT
LIFT BRIDGE
CYHD. PWR. CAB.
OVERHEAD CAB.

travel per foot of tidal rise. Calculated tidal fluctuation (rise) was 4.9 feet during that period.

The dyed water mass which entered the Eureka channel split into both Indian and Eureka Inner Reach channels. The leading edge of the mass in Indian channel reached the cable crossing by 0955, two hours and 40 minutes after injection started (Figure 13). The eastern-most extension of that mass was at the eastern end of oyster culture area "A" by 1115, four hours after the release. This represented a movement of 8229 yards, an average velocity of 34.3 yards per minute, and 1679 yards of travel per foot rise in tide.

That eastern-most extension of the Eureka channel water mass was assumed to be from the Murray Street STP injection, however the possibility that the Hill Street STP dye from two days previous interferred with the measurements does exist. The relative concentrations of dye in the channel, however, point to that as a very remote possibility.

Fog and drizzle made aerial observation difficult, so the dye injection rate was doubled at 0840. This made estimation of the dilution rates largely impossible. A plot of dye concentration versus distance from the outfall gives one an indication of dilution rates, however (Figure 14). The majority of dilution in the Samoa channel occurred from the outfall to the confluence with Eureka channel (@ 1900 yards) and from midway up the Samoa channel to Bird Island (from a distance of 2800 to 5100 yards). The section of Indian channel from the western end of Woodley Island to oyster culture area "A" (from a distance of 2900 to 4600 yards) accomplished the largest measured dilution (Figure 14).

Figure 15 is a synopsis of the plant flow, dye use, and calculated outfall dye concentrations during the injection. Note the increase in dye concentration beginning at 100 minutes from the initiation of the injection (time 0).

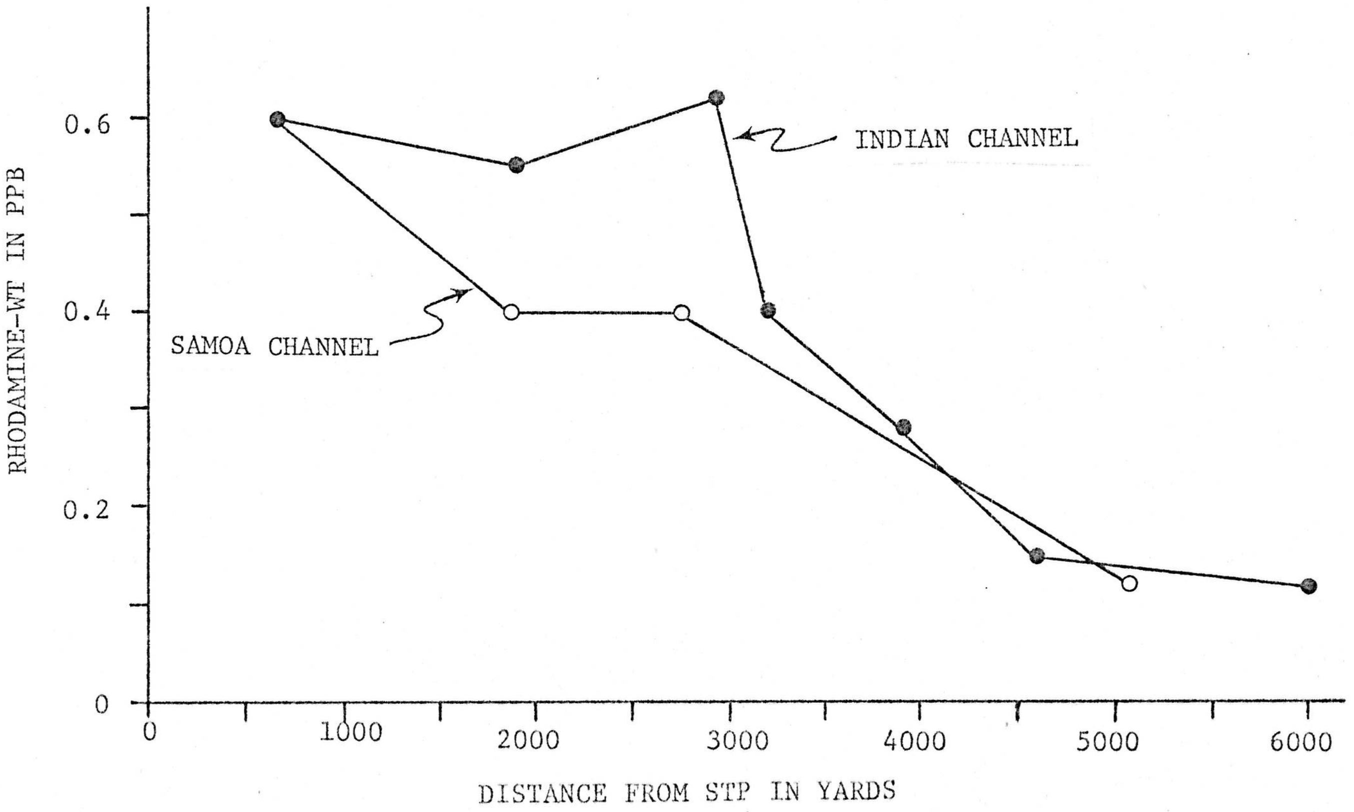


Figure 14. Rhodamine-WT concentration versus distance from the Murray Street STP outfall during the April 26, 1979, short-term dye injection study.

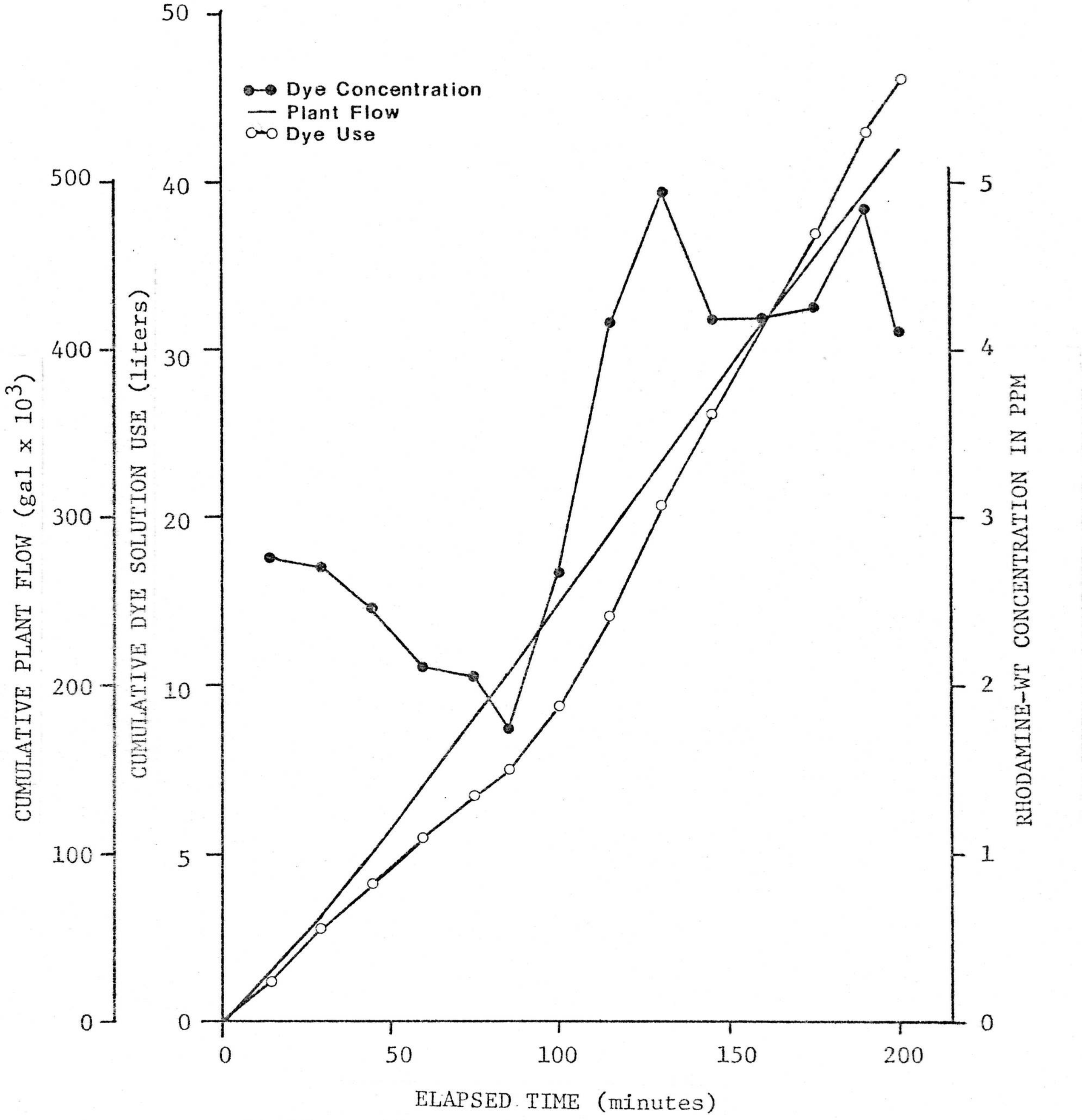


Figure 15. A synopsis of cumulative plant flow, cumulative dye use, and dye concentration at the Murray Street STP outfall during the April 26, 1979, short-term dye injection study.

DISCUSSION

The results of this study have further reinforced earlier findings that effluent from any of the three STP's studies will reach the commercial oyster culture areas within any one tidal cycle. The Hill Street STP release correlated closely with a study done in April of 1978. During that study a release from the STP was followed through one half of the ebb tide until it reached the western tip of Woodley Island. Another dye cloud was formed the following day at the tip of Woodley Island at low tide using a boat-borne dye release system. That cloud was then followed through most of the flood tide. Within two hours and 15 minutes of flood tide the dye cloud had moved up Indian channel to the oyster culture area "A" in south Arcata Bay.

The dilution ratios of this study also agree with the prior study of the Hill Street STP. During the 1978 study the dilution at the confluence of Eureka and Daby Sloughs, in Eureka Slough, was 1:200, and 1:1264 at the Shell Dock in Eureka Inner Reach. Dilutions at those two points during the 1979 study were 1:250 and 1:1500, respectively.

In terms of threat to the oyster culture areas, a raw sewage spill, dependent on tidal cycle, would reach the areas. A portion of the water over the culture areas at any time is composed of effluent from the plants. Should a spill occur at the Hill Street STP during a flood tide with a rise of three feet or more, diluted raw sewage would reach oyster culture area "A" near the Brainard Mill in south Arcata Bay in less than six hours. Were the spill to occur during an ebb tide, the sport harvest of clams along Woodley Island and Indian Island would be jeopardized with three hours.

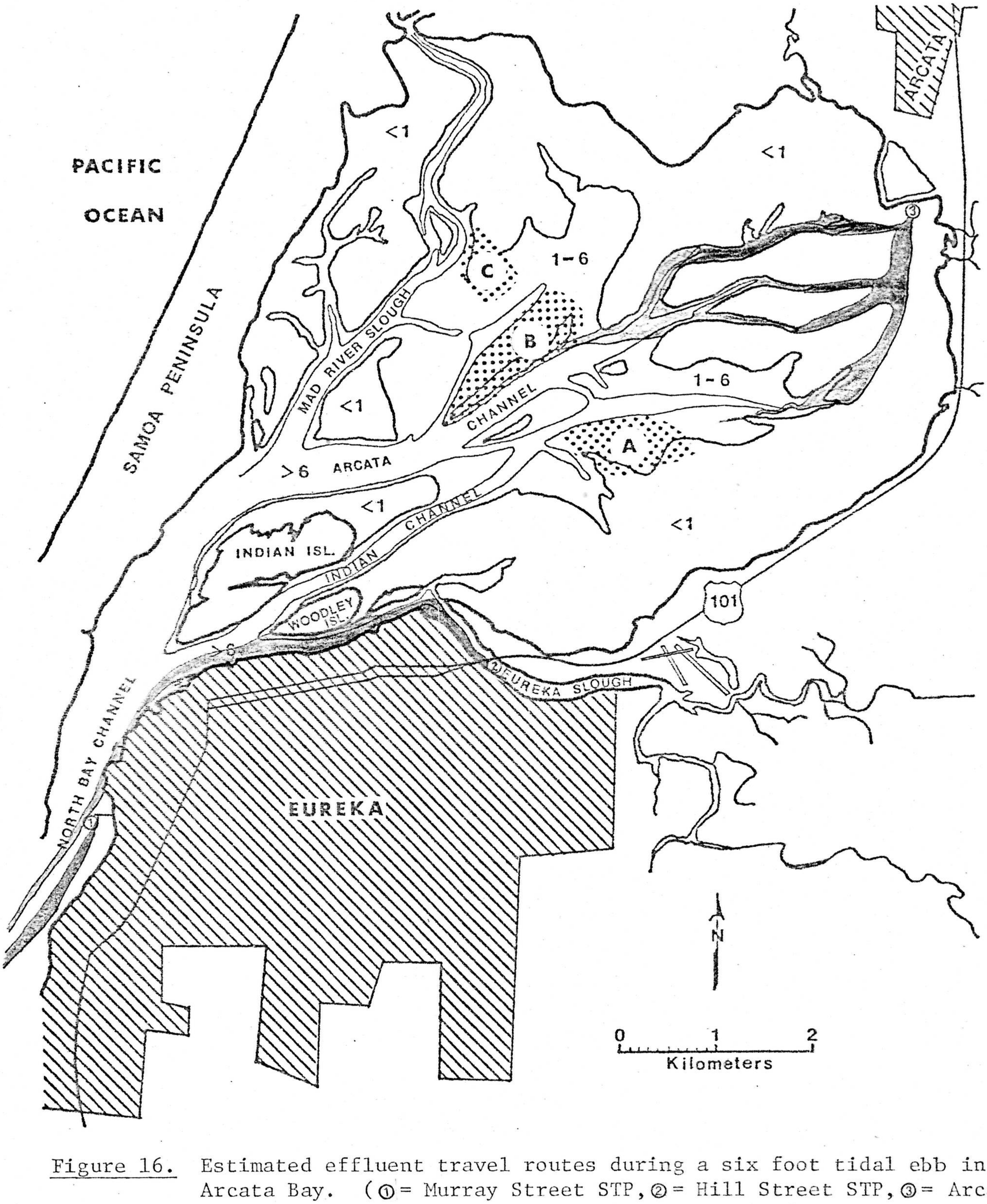
The Arcata STP dye injection also showed that effluent from that plant will reach oyster culture areas during tidal ebb, dependent on tidal height. The 1979 study results on travel times and travel routes of dyed water from the STP correlate well with those from earlier studies. The travel times from the STP to the oyster culture areas "A" and "B" during the 1979 study were within four and a half hours of ebb tide. Travel to the same areas in 1977 was accomplished within five hours of ebb tide. Tidal height fluctuations were about six feet during both studies.

Any tide of five foot drop or more will result in Arcata STP effluent reaching those oyster culture areas. A raw sewage spill from the plant on any five foot ebb tide could be expected to reach oyster culture area "B" within five hours. Based on the 1979 study, that mass of water could also be expected to remain, although somewhat diluted, as long as two tidal floods later. The danger of contamination from sewage to the commercial oyster harvest in that area is indeed established.

Travel times for dyed water from the Murray Street STP showed that effluent would reach oyster culture areas "A" and "B" within four hours on a flood tide of five foot rise. Given the normal five and one half hours of tidal flood, one could expect the effluent to reach oyster culture area "C" by the end of the tidal rise. It is evident that a raw sewage spill from the Murray Street STP during a flood tide of five foot rise or more would jeopardize the harvest from all three oyster culture areas, dependent on the timing of the spill.

Combination of the results from the three dye injection studies of April, 1979, presents a more complete picture of effluent travel routes through a tidal cycle. A six foot tidal drop would carry effluent in the ebb from 1) the Arcata STP to oyster culture areas "A" and "B", 2) the Hill Street STP to clamming areas on Woodley and Indian Islands and on towards the mouth of Humboldt Bay, and 3) the Murray Street STP to clamming areas near Bucksport and on out the mouth of Humboldt Bay (Figure 16).

The subsequent flood tide would carry any diluted effluent that did not exit the bay, plus a dose of fresh effluent, up the tidal channels to Arcata Bay. Effluent from Murray Street STP would move over the clamming areas of Woodley and Indian Islands and on to oyster culture areas "A", "B", and "C" (Figure 17). That same tidal flood would carry effluent from Hill Street STP to oyster culture "A" and up Fay and Freshwater Sloughs, and effluent from Arcata STP into the northeast corner of Arcata Bay and Gannon, Jacoby, and Washington Gulch Sloughs (Figure 17). It becomes evident from these results that through a few tidal cycles Arcata Bay becomes/is a mixture of bay water and effluent in differing concentrations and ages dependent, in part, on STP flow rates, freshwater input to the bay, residence time of the effluent, and tidal fluctuations. The following


PACIFIC OCEAN
SAMOA PENINSULA
ARCATA
<1
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C
B
A
MAD RIVER SLOUGH
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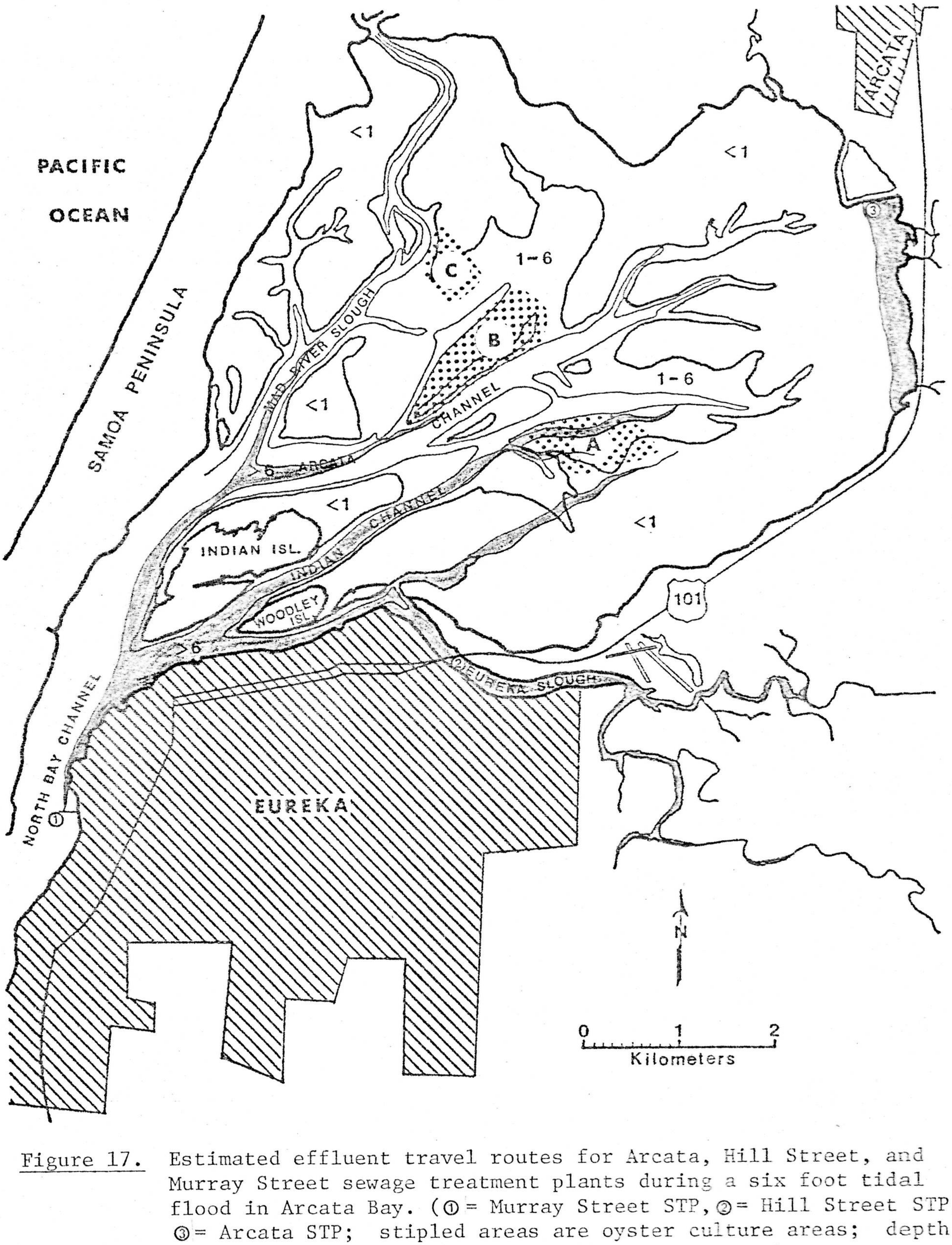
1-6
CHANNEL
>6 ARCATA
<1
<1
INDIAN ISL.
INDIAN CHANNEL
WOODLEY ISL.
101
>6
EUREKA SLOUGH
NORTH BAY CHANNEL
EUREKA
①
②
③
N
0 1 2
Kilometers

Figure 16. Estimated effluent travel routes during a six foot tidal ebb in Arcata Bay. (① = Murray Street STP, ② = Hill Street STP, ③ = Arcata STP; stipled areas are oyster culture areas; depth curves are in feet, datum is mean lower low water)


PACIFIC
OCEAN
SAMOA PENINSULA
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1-6
1-6
C
B
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MAD RIVER SLOUGH
ARCATA CHANNEL
>6
INDIAN ISL.
INDIAN CHANNEL
WOODLEY ISL.
>6
101
②EUREKA SLOUGH
③
NORTH BAY CHANNEL
①
EUREKA
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0 1 2
Kilometers

Figure 17. Estimated effluent travel routes for Arcata, Hill Street, and Murray Street sewage treatment plants during a six foot tidal flood in Arcata Bay. (① = Murray Street STP, ② = Hill Street STP, ③ = Arcata STP; stipled areas are oyster culture areas; depth curves are in feet, datum is mean lower low water)

questions remain: "What are those effluent concentrations? Do they constitute a hazard to sport and commercial shellfish harvest?

For any raw sewage spill from any of the STP's, it is evident that a threat exists. The duration of that threat is presently unknown. The answers to those questions await a more comprehensive study of circulation and flushing of Arcata Bay with those specific objectives in mind. It would be desirable in such a study to attain a "steady state" dye concentration in Arcata Bay, most logically derived from injection of dye into all of the STP outfalls through several tidal cycles. The movement and dilution of the different water masses could then be followed by fluorometry through successive tidal cycles.

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1978. Hill Street STP Dye Study - Humboldt Bay. Office Memo by Bob Klamt dated April 5, 1978: 6pp mimeo.

N. Coast Reg. Water Qual. Control Board
1977. 1977 Dye Study Program. Office Memo by John Hannum, undated: 21pp mimeo plus slides.

N. Coast Reg. Water Qual. Control Board
1974. Arcata Bay Preliminary Wastewater Movement Study. Office Memo by John Hannum dated October, 1974: 12pp mimeo plus tape and slides.

APPENDIX

A discussion of two different methods for calculating concentrations of Rhodamine-WT in water is presented. The author realizes that the studies presented in this report were affected to a degree by the method of dye concentration calculation. The need to rationally express the concentration of Rhodamine-WT in water is an important requirement in all studies involving dye tracers. The discussion and recommendations contained herein satisfy, in the author's mind, that requirement.

One of the factors involved in work with Rhodamine-WT as a fluorescent tracer in hydrologic studies is the convention and/or logic of expressing dye concentration. There is a need for a conventional and logical expression of dye concentration which minimizes mathematical manipulation and analytical error. The practice (a "convention" since the early Chesapeake Bay studies) of using the "specific gravity" and "percent by weight" of "active" dye to arrive at "concentration" (weight of dye per volume) must now be questioned from the standpoints of its introducing: 1) extra mathematical manipulations and 2) significant errors into calculations of concentration. Moreover, since few studies use "dry" dye formulations, the practice has little rational base except "tradition".

To emphasize those points the following exercise is presented:

> The equation by which Rhodamine-WT concentration was calculated in the April, 1979 studies was based on a "specific gravity" for the dye of 1.2 and a dye "solution strength" of 20% dry dye by weight:
>
> Kg dry dye = liters dye solution X 1.2 X 0.20.
>
> The resultant calculated weight of "dry" dye was then used to calculate "concentration on a weight:weight basis (Furfari, 1978).
>
> Correspondence with the du Pont de Nemours and Company (letters included in this Appendix) revealed that:
>
> 1) Rhodamine-WT liquid is made to specific gravity of 1.15± 0.05 not 1.2;
>
> 2) The "strength" of each new lot of Rhodamine-WT liquid is standardized by dilution with water to a spectral absorbance (not fluorescence) which is 100± 5% of that of a standard lot of du Pont Rhodamine-WT liquid. The standard is du Pont's Lot 69;
>
> 3) Dye Lot 69 was compared spectrophotometrically (not fluorometrically) against a 21.33% solution made up from a laboratory purified dry powder dye;
>
> 4) Neither Lot 69 nor the laboratory purified dry powder dye are available, however the values for relative strength of each new dye lot versus Lot 69, as determined spectrophotometrically (not fluorometrically) are available from the company;
>
> 5) Fluorescence of a dye lot probably varies as much as the spectral absorbance used to standardize the lot.

To calculate the "concentration" of Rhodamine-WT in water using the convention and assuming specific gravity of 1.2 and a solution strength of 20% by weight results in the following errors:

1) ± 4.35% variation from specific gravity variation of dye lot,
2) 6.24% underestimation from percent strength difference,
3) ± 5% variation from standardization of each new lot,
4) assumption that percent strength by spectrophotometric determination is the same as by fluorometric determination.

To eliminate the above-cited errors and what has become a non-rational tradition, the author proposes that future work with Rhodamine-WT liquid use the following logic in calculations of concentration:

> Identify each lot of Rhodamine-WT liquid as: full strength dye. That full strength dye can then be volumetrically diluted to obtain fluorometric standards on a volume:volume basis, thus eliminating one step in mathematical calculations and three sources of variability in the expression of concentration. When the Rhodamine-WT liquid must be adjusted to match the density of the to-be-studied water mass, the volume:volume relationship must be adjusted accordingly.

Comparison of results obtained via the "old" convention could be accomplished, if one desired, by reducing the "old" results to a volume:volume basis: back-calculating through the equation originally used to express concentration on a weight:weight basis.

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A-3

STATE OF CALIFORNIA—RESOURCES AGENCY
EDMUND G. BROWN JR., Governor

CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD—
NORTH COAST REGION
1000 CODDINGTOWN CENTER
SANTA ROSA, CALIFORNIA 95401
Phone: 707—545-2620

May 25, 1979

E.I. duPont de Nemours, Inc.
1007 Market Street
Wilmington, Delaware 19898

Gentlemen:

Beginning with the Chesapeake Bay hydrology studies, the weight of a dye tracer in a volume of water became the dilution-diffusion base for dye tracer studies.

With the production of aqueous dye solutions, specifically Rhodamine-WT, a similar "logic" has been applied, using the "20%" from the duPont dye product label to say: "the product is 20% dye by weight".

Moreover, the specific gravity of the aqueous product has been used as a factor in further calculations of the type: "1 liter of product x 20% x S.G.= ________ kilograms of "dye."

We are dissatisfied with this procedure in today's use of duPont Rhodamine-WT solutions because:

1. the label states the tinctorial strength of the solution as determined spectrophotometrically is a minimum of 20% of that of a Rhodamine-B standard;

2. the specific gravity is a lot-to-lot variable about a central value of 1.15; and

3. duPont's comments on the product label advise the user to calibrate the product fluorescence with each lot used.

The disturbing fact to us is that some users of your product continue to follow the Chesapeake precedent: (1) calibration is to use 20% by weight times specific gravity to obtain the weight of "dye", and (2) measurement is to use fluorometry based upon the above calibration "logic".

Contrary to the Chesapeake precedent, we have been in the practice of specifying each lot received "full strength" dye and calibrate accordingly. This was done in an effort to: (1) get around the use of factors for which there is no convincing basis, and (2) do away with the possible lot-to-lot variability in fluorescence by a not mixing lots in calibration or use.

Our questions to you are an attempt to settle the dispute concerning the two types of logic: (1) 20% x S.G. = weight of "dye" with wt/wt calibration of fluorescence; vs: (2) volume/volume calibration by lot specifying each lot as "full strength".

The specific statements we need clarified are:

1. Rhodamine-WT as shipped in aqueous solution is not 20% "dye" on a weight-to-weight basis;
2. the 20% tinctorial strength means the product produces a spectrophotometric response (absorbance) equivalent to 20% of that produced by a Rhodamine-B standard;
3. the gyrations of applying a 20% "active ingredient" factor and a specific gravity factor in calculating the actual weight of "dye" are senseless if #1 and #2 are true.

Your comments on this problem and reply to the above statements would help immensely in solving the problem of determining what is the correct method of calibration of Rhodamine-WT concentrations. Thank you for your help and consideration.

Sincerely,

Robert R. Klamt
Environmental Specialist

CH-1

DU PONT
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ESTABLISHED 1802
E. I. du Pont de Nemours & Company
INCORPORATED
Wilmington, Delaware 19898

CHEMICALS, DYES AND PIGMENTS DEPARTMENT
Technical Laboratory

WATER QUALITY
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☐ JW
☐ TV
☐ RRK
☐ Reply

Bingo!

June 6, 1979

Mr. Robert R. Klamt
California Regional
Water Quality Control Board
North Coast Region
1000 Coddingtown Center
Santa Rosa, CA 95401

Dear Mr. Klamt:

This is in response to your recent letter on the subject of Du Pont Rhodamine WT Liquid and its use in tracer studies.

When Rhodamine WT was first introduced, Du Pont Rhodamine B was already an established product in water-tracing work, and it was natural to define the Rhodamine WT concentration in terms of the established product. The spectral absorbance and fluorescence of the two dyes are enough alike so that procedure apparently gave acceptable results. However, I agree with you that a more suitable procedure for precise scientific work would be to use only one Lot of Du Pont Rhodamine WT Liquid in any given study, and use the dye as received as the "full strength dye" for that particular study. Whether the initial measurement of the "full strength" dye is volumetric or gravimetric would seem to me to be a matter of personal preference.

To respond to some of your specific questions and comments, let me list some facts about our product and our procedures in preparing it for sale.

1. To de-emphasize the original reference to Rhodamine B, the official name of our product is now Du Pont Rhodamine WT Liquid rather than the earlier name, Du Pont Rhodamine WT Solution 20%.

2. Each Lot of Du Pont Rhodamine WT Liquid is standardized by dilution with water as required so that the spectral absorbance is 100 ± 5% of that of a standard lot of Du Pont Rhodamine WT Liquid. The sample used in the spectrophotometric determination is weighed, made up to a fixed volume, and then diluted volumetrically.

3. The Standard Lot of Du Pont Rhodamine WT Liquid was Lot 69. Spectrophotometric comparisons of that Lot versus a laboratory purified dry powder dye sample indicated an active ingredient content of 21.33%. Neither Lot 69 nor the dry powder laboratory purified standard are now available. For any specific Lot, our figures for active ingredient content or relative strength versus Lot 69 can be supplied upon request.

4. Specific gravity of the product, according to our specification, will be 1.150 ± 0.050. This figure is of interest only if one wishes to measure the full strength dye volumetrically but express its concentration in grams per liter or similar units.

5. In our standardization procedures we make no measurements of fluorescence. It is logical to assume that it varies at least as much as the spectral absorbance.

In summary, Du Pont Rhodamine WT Liquid may have lot-to-lot variations in spectral absorbance, specific gravity, and fluorescence. Therefore, it seems logical to use material from a single dye Lot in a given tracer study and to assume the material as purchased as 100% dye for that study, with appropriate dilutions of that material for calibration purposes.

I hope these comments will be helpful. If I have not succeeded in clarifying the situation with respect to our standardizations of Du Pont Rhodamine WT Liquid, please do not hesitate to write again.

Sincerely yours,

Ira L. Hall

Ira L. Hall
Specialty Dyes

ILH:lv