NH Work Task 91-7.11

HAMPTON HARBOR DYE RELEASE STUDY

JUNE 1993

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DIVISION OF PUBLIC HEALTH SERVICES

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JUNE 1993

CONTRACTOR

FUGRO MCCLELLAND EAST, INC.

PORTSMOUTH, NH

SUBMITTED TO

OFFICE OF STATE PLANNING

NH COASTAL PROGRAM

BY

PAUL RAICHE AND JOHN SEIFERTH

FOOD SANITATION SECTION

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HAMPTON HARBOR DYE RELEASE STUDY

DIVISION OF PUBLIC HEALTH SERVICES

Prepared by Paul Raiche and John Seiferth

The objective of this study as stated in the "Proposal For Work Task" submitted to the Office of State Planning (OSP) on November 12, 1992 basically was twofold. The first objective was to determine to what extent a raw or partially treated discharge from the Hampton Wastewater Treatment Plant (HWTP) would affect the shellfish beds located in Hampton Harbor. Secondly, based upon the report DPHS would determine the placement of a closed safety zone based upon time of travel of the dye in the harbor.

The contractor selected for the study was Fugro-McClelland (East), Inc. of Portsmouth, New Hampshire. Their report is included as exhibit A. Figure 7 of their report illustrates the minimum time of travel (time "A") and shows that any possible release of a pollutant from the HWTP would not reach their stations 6, 7 & 8 in less than one tidal cycle (approximately six hours). Releases at slack high tide are considered to be the worst case scenario since under any other tidal stage, the "pollutant" would not travel as far prior to the tide change.

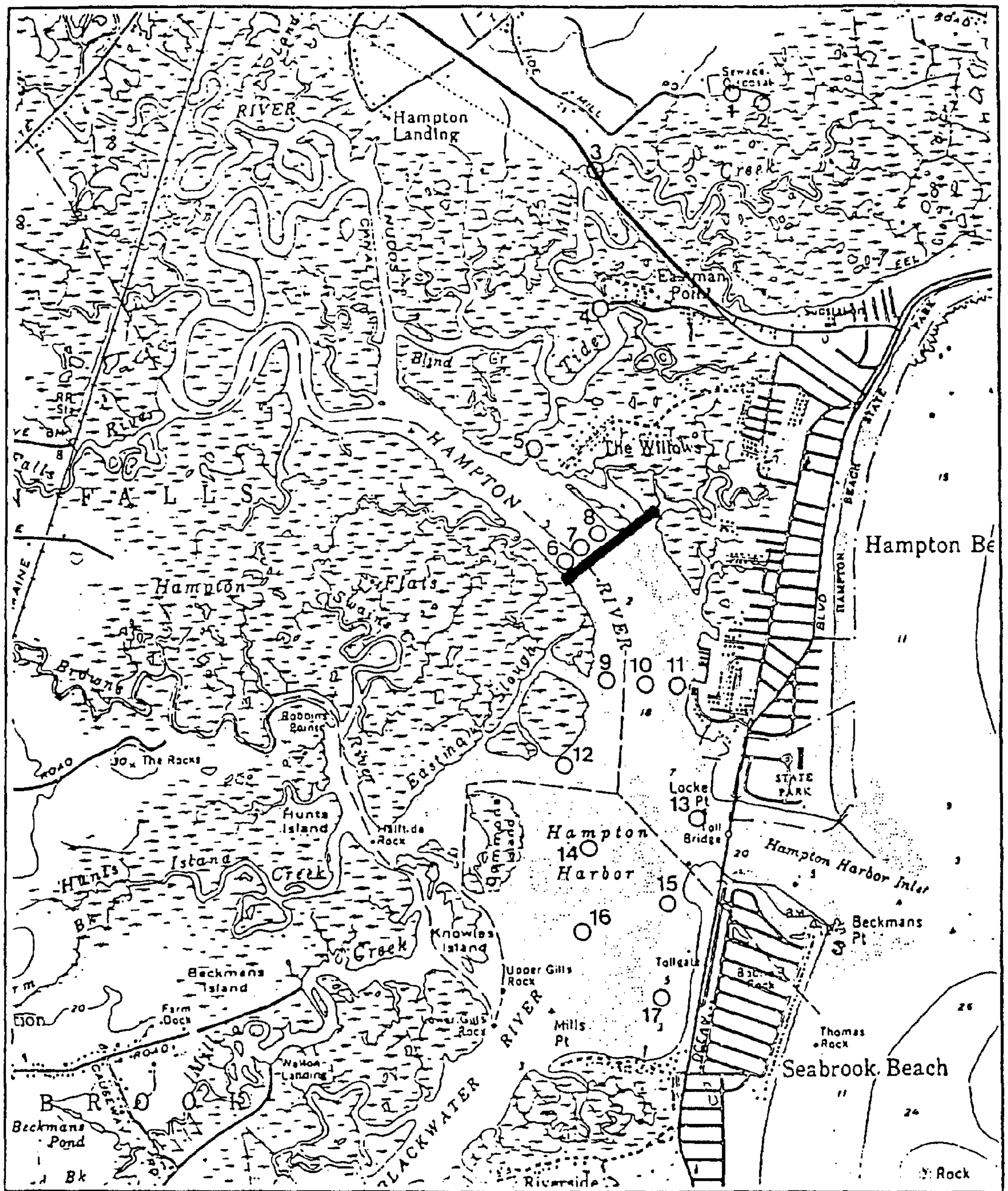
Fugro-McClelland concluded that any "pollutant" released from HWTP would be diluted 50-100 times by the time it reached the end of Tide Mill Creek. They then state that "at least twice the dilution" as occurred in Tide Mill Creek could be expected to occur in Hampton River. This dilution, coupled with a change of tide and some amount of die-off, would result in an assumed load of 2 million fecal coliforms/100 ml. being diluted to less than 10 fecal coliforms/100 ml. at points beyond stations 6, 7 & 8.

During 1993, DPHS collected water samples in the study area in order to determine if there was a correlation between observed water quality and the dye release study. The number of samples taken was significantly higher than in previous years. Under dry weather conditions, defined as less than 1/4 inch rain during the previous two days, the samples indicate that there is little pollution found downstream of stations 6, 7 & 8. This agrees with the findings of the dye release study.

A shoreline survey was conducted on June 14, 1993 of the populated area around Tide Mill Creek and Hampton River. The results of that survey found no variations from the Hampton Harbor Sanitary Survey Report (Exhibit 2) conducted by the Department of Environmental Services (DES) in April of 1992. These surveys show no other significant pollution sources other than the treatment plant. The dye release study, therefore, is the dominant factor in determining the location of the closed safety zone.

As a result of the Fugro-McClelland report all of Tide Mill Creek and that portion of Hampton River upstream of stations 6, 7 & 8 should be permanently closed to shellfishing. The report indicates that this area is influenced by the HWTP within a six hour time span while the rest of the harbor would not be similarly influenced in less than 11.5 hours. Furthermore, any discharge that might occur would be diluted to acceptable levels prior to reaching those shellfish beds located downstream of the proposed closure line. Figure 1A shows the proposed line which would separate the closed safety zone from the open areas. The area north and northwest of that line will be included in the closed safety zone. This includes all of Tide Mill Creek, Hampton Falls River and Hampton River.

A Memorandum of Understanding will have to be developed among DPHS, DES and the HWTP. This MOU will have to stipulate the time frame for reporting any upset at the plant to the division and the time frame by which the harbor must be closed to shellfishing. The total time from the occurrence of the upset to the actual posting of the area should not exceed the 11.5 hours referred to in the report. Also, a Memorandum of Understanding is presently being formulated between the Office of State Planning, the Department of Environmental Services, The Department of Health and Human Services and The Department of Fish and Game which will delineate the actions to be taken prior to July 1, 1994 in order to determine the classification of Hampton Harbor.



	PROPOSED LINE OF PERMANENT CLOSURE	PREPARED FOR THE NH DEPT. OF PUBLIC HEALTH SERVICES, 6 HAZEN DRIVE CONCORD, NH 03301	FIGURE 1A
USGS Hampton, NH 7.5 Min. Series	Hampton Harbor Dye Study, Wastewater Effluent Time of Travel, Hampton, NH	May 1993 / Job No. 16167999	FUGRO McClelland

HAMPTON WASTEWATER TREATMENT FACILITY DYE STUDY

Objectives:
The primary objective of this study is to estimate the time of travel for effluent from the Hampton wastewater treatment facility to various known shellfish beds in the Hampton River and Hampton Harbor, as required by the National Shellfish Sanitation Act. Secondarily, the dilution factors associated with travel to these shellfish beds are of interest.

Approach:
The study approach has been detailed in the submitted work plan. It basically consists of introducing rhodamine dye (Intracid Rhodamine WT Liquid) at an elevated concentration to the dechlorination tank at the Hampton wastewater treatment facility at high tide and tracing the movement of the dye through the ensuing tidal cycle by fluorometric measurement. Stations were established at the input point, slightly downstream of the effluent outfall, at three points along Tide Mill Creek, and at multiple locations in the Hampton River and Harbor. Once dye was detected at a station, a sampling crew monitored the increase in fluorescence level for half an hour or until the level stabilized (whichever came first), then moved to the next station downstream. Additional grab samples were collected and fluorometrically tested later as warranted by conditions in the system. Of particular note was the change in tide, which moved much of the dye back upstream during the second half of the study period. This upstream movement was tracked when it became apparent that no further downstream movement would occur during the selected tidal cycle.

For each station sampled, a graph of concentration over time was prepared. From these graphs it is possible to estimate the time of travel from the treatment facility outfall to any of the sampled stations. A dilution factor range under the tidal conditions of the test has been calculated for each station, allowing some prediction of the resultant concentration of a discharged pollutant at any sampled station.

Results:
Dye Input (Stations 1 & 2)
Rhodamine dye (Intracid Rhodamine WT Liquid) was introduced into a small mixing chamber just after dechlorination at the wastewater treatment facility. Effluent moves from this point directly into the discharge pipe. The outflow dye concentration was to be at least 1000 ppb, held as constant as possible over a three hour input period. Actual concentrations leaving the dechlorination chamber varied from 2300 to 3100 ppb. Discharge varied substantially during the dye input period (5:20 AM to 8:50 AM), largely as a consequence of spanning the period when most people wake up and begin water use. Flows varied from 0.8 to 4.7 cfs, corresponding to daily flow levels of 0.8 to 3.1 mgd. Input rate for the dye, which was premixed at 240 million ppb, was varied from 25 to 64 ml/min in an effort to achieve outflow concentrations of 2300 to

2500 ppb. The 3100 ppb level resulted from a combination of low flows (0.8 mgd) at the start of the dye input and a minimum dye input rate of 25 ml/min. Once the discharge began to increase, input concentrations were checked and adjusted as necessary in response to flow measurements at the wastewater treatment facility during the dye addition to maintain the most constant effluent concentration possible.

On Thursday, May 27, 1993, the high tide at the treatment facility occurred slightly after 5 AM. Dye input commenced at 5:20 AM at the time of the first noticeable downstream movement of water in the receiving tidal channel, and continued for 3.5 hours, spanning a major decrease in channel volume in response to the outgoing tide. Monitoring started at the initiation of dye input and continued for about nine hours, several hours after it became apparent that no further dye inputs to the Hampton River would occur during that tidal cycle. Monitoring stations are shown in Figure 1. Station 1 is the discharge (as the effluent enters the discharge pipe from the mixing chamber), while station 2 is 100 ft downstream of the discharge point in the tidal creek.

Background fluorescence was less than 5 units at stations 1 and 2 prior to dye addition. The initial dye concentration in the dechlorination chamber ranged from 1013 to 2215 units, but it should be remembered that mixing was not complete until the dye exited the chamber and the fluorometer is not designed to accurately read measurements above 500 units. Actual dye concentration was maintained at 2300 to 2500 ppb for most of the input period.

The high water level in the tidal creek during high tide caused surcharging of the outfall pipe and substantial dilution of the dye before the effluent was actually discharged into the creek. The surcharging also greatly slowed the initial discharge of dye-laden effluent; it was at least 0.7 hours before dye reached station 2 at any appreciable concentration (Table 1, Figure 2). Dye was clearly visible 0.9 hours after input. For several hours after high tide, while the creek channel volume was still high, the dye concentration at station 2 was <100 units, suggesting at least a tenfold (and possibly as much as forty-fold) dilution factor at station 2. As the creek volume decreased with lowering tide, the travel time of dye in the discharge pipe declined to under 10 minutes and the dilution factor decreased drastically. In the last hour of dye addition the concentration at station 2 increased to over 200 units, with a high of 500 units. This suggests a minimum dilution factor of 2 to 10 at station 2.

Activity at the Rt. 51 Bridge (Station 3)

Fluorescence began to rise at station 3, the Route 51 bridge, at about 7:30 AM, slightly more than 2 hours after dye input began and over an hour after dye reached station 2 (Table 1, Figure 3). The rhodamine dye does not become visible until a concentration of about 20 units is reached, while background levels were less than 10 units, so there is a visibly undetectable range over which the dye concentration increases as the dye front approaches a station. The dye became visible at station 3 at about 8:30 AM, about 3 hours after dye addition began, 2 hours

Fugro McClelland

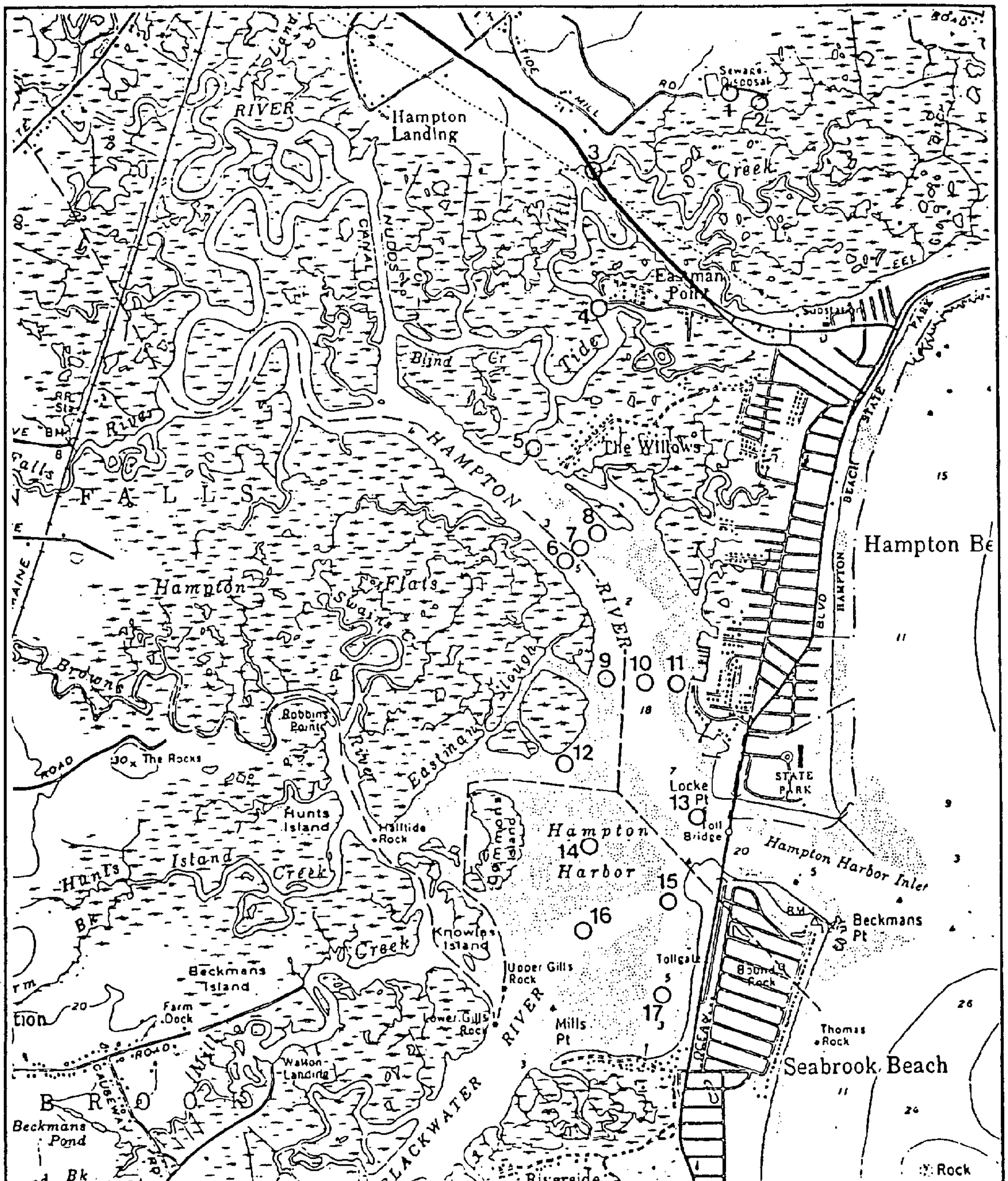
TABLE 1

RELATIVE FLUORESCENCE (UNITS) OVER TIME AND SPACE

IN THE TIDE MILL CREEK/HAMPTON RIVER SYSTEM

ON MAY 27, 1993

Military Time	Time (hr)	Station 2	Station 3	Station 4	Station 5	Station 8
	0.0					
	0.1					
5:30	0.2	2.6				
	0.3					
	0.4					
	0.5	3.8				
	0.6					
6:00	0.7					
	0.8					
	0.9	47				
	1.0					
	1.1					
6:30	1.2					
	1.3					
	1.4					
	1.5					
	1.6					
7:00	1.7	57				
	1.8					
	1.9		5.3			
	2.0		5.4			
	2.1		6			
7:30	2.2		7			
	2.3		8.6			
	2.4		8.8			
	2.5		9.5			
	2.6	500	12			
8:00	2.7		12.3			
	2.8	253				
	2.9	291				
	3.0	340				
	3.1		18.4	5		
8:30	3.2		19.6			
	3.3		20.9			
	3.4		37	8		
	3.5		38			
	3.6		40			
9:00	3.7	123		12.3	5	
	3.8			13.9		
	3.9			14.6		
	4.0			15.8		
	4.1			17.9		



USGS Hampton, NH 7.5 Min. Series	SITE LOCUS Hampton Harbor Dye Study, Wastewater Effluent Time of Travel, Hampton, NH	PREPARED FOR THE NH DEPT. OF PUBLIC HEALTH SERVICES, 6 HAZEN DRIVE CONCORD, NH 03301 May 1993 Job No. 16167999	FIGURE 1 FUGRO McClelland

Military Time	Time (hr)	Station 2	Station 3	Station 4	Station 5	Station 8
9:30	4.2	5.8		20.6		
	4.3			21.8	12	
	4.4			24.7		
	4.5			27.7		
	4.6			29.1		
10:00	4.7	2.8		29.7		
	4.8			30.4		
	4.9		30	30.4		
	5.0			28.9	23.4	9.5
	5.1					
10:30	5.2					9.5
	5.3					
	5.4					
	5.5					
	5.6					
11:00	5.7					
	5.8					
	5.9					
	6.0					
	6.1					
11:30	6.2				27.2	
	6.3					
	6.4			28.5		
	6.5		12		10.4	
	6.6					7.6
12:00	6.7			29	5.5	
	6.8					
	6.9					
	7.0					
	7.1					
12:30	7.2		25.3			
	7.3			11.7		
	7.4				2.4	
	7.5					
	7.6					
13:00	7.7	11				
	7.8					
	7.9		36			
	8.0			8.2		
	8.1				6.6	
	8.2					
13:30	8.3					
	8.4					
	8.5					
	8.6					
	8.7					
14:00	8.8		10			
	8.9					

FIGURE 2

FLUORESCENCE OF RHODAMINE DYE AT STATION 2

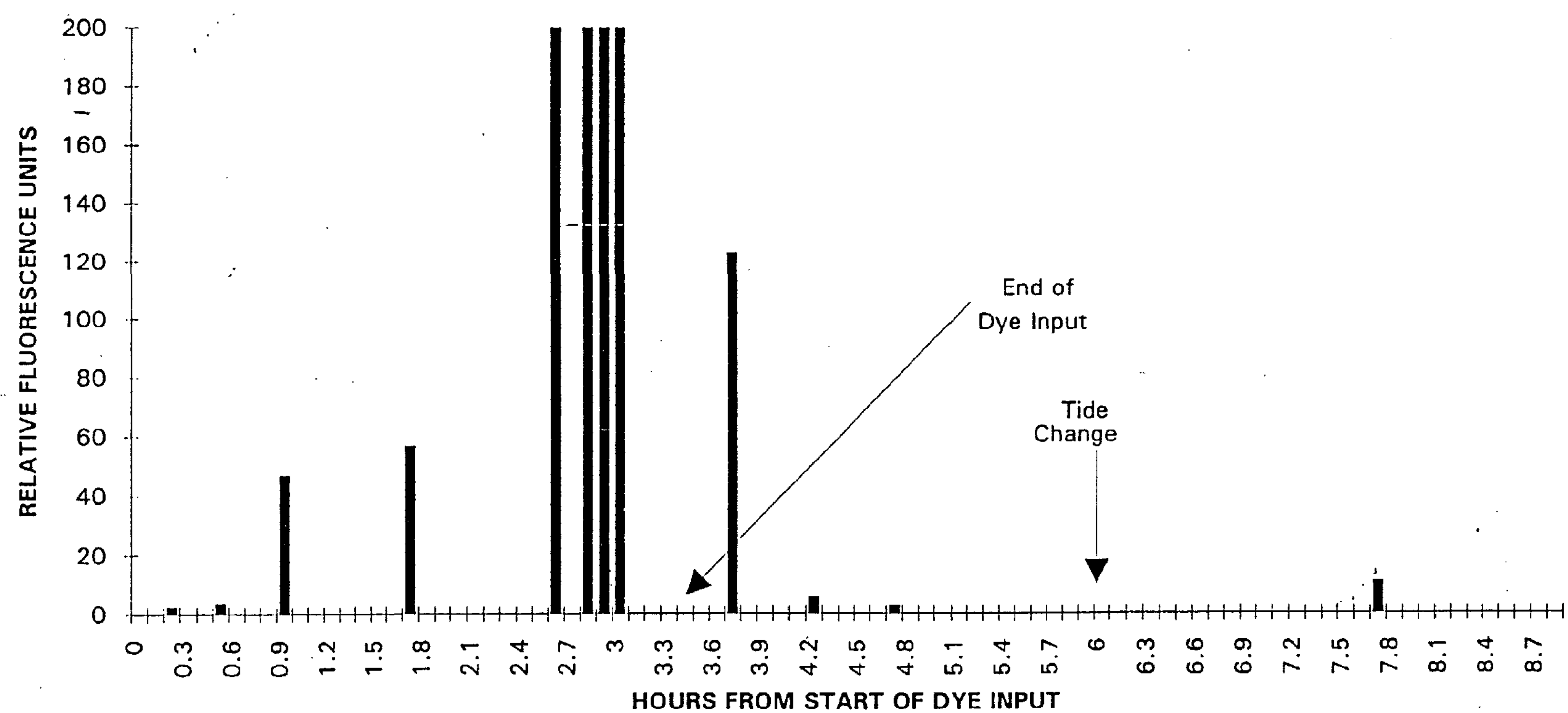


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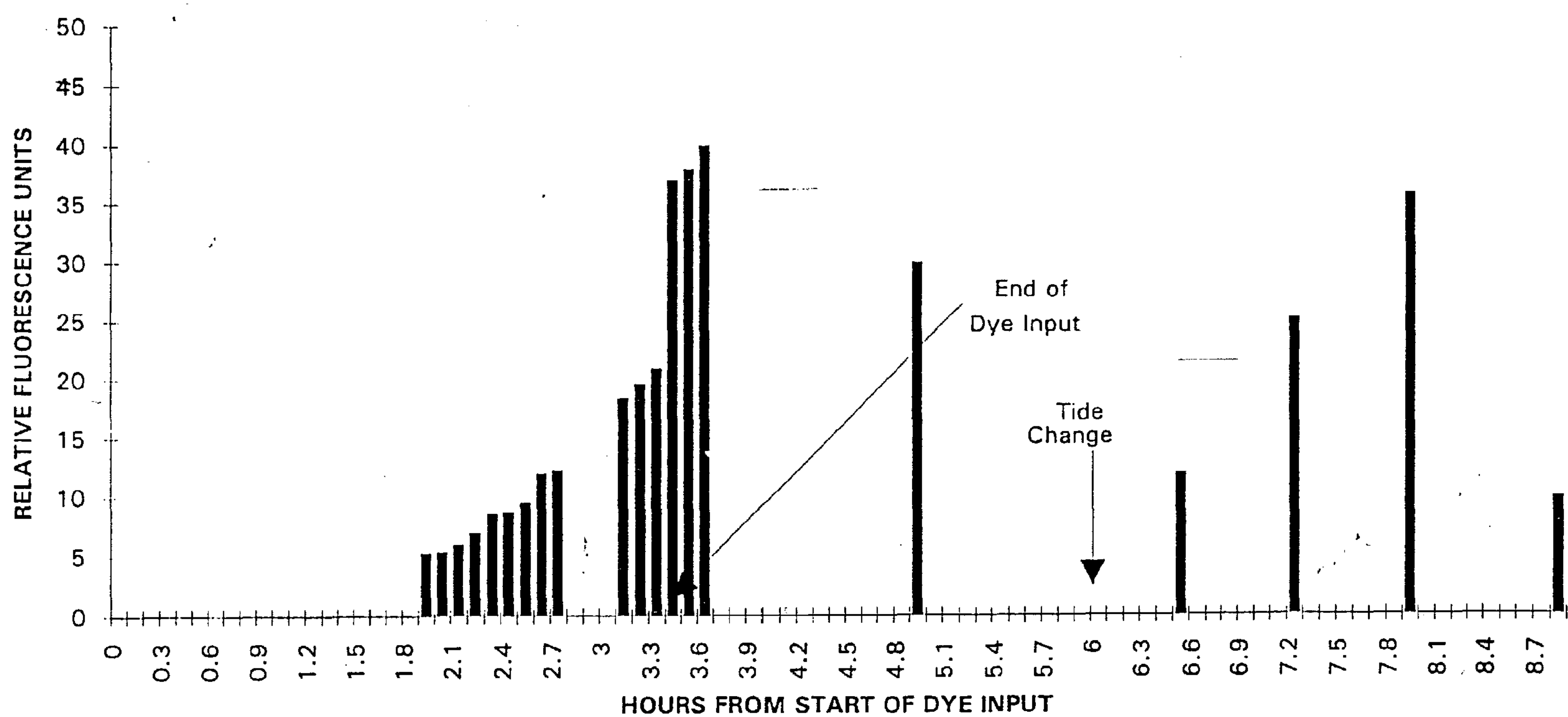
FIGURE 3

FLUORESCENCE OF RHODAMINE DYE AT STATION 3



after the dye reached station 2, and an hour after the first evidence of fluorescence increase at station 3. Fluorescence rose quickly, peaking at 40 units shortly before 9:00 AM.

Although only visual examination was performed for the next hour or so (the fluorometer was moved to station 4 and the visibility of the dye precluded the need for sampling), dye concentrations appeared fairly stable for the next 1.5 hours. A value of 30 units was recorded at 10:12 AM, after which there was a decline in fluorescence to 12 units by 11:48 AM. The trailing end of the visible dye pulse seemed to pass station 3 about 3 hours after the leading edge reached that station. The elapsed time between the first apparent indication of a fluorescence increase and the minimum value detected after the peak was about 4.5 hours, about an hour longer than the duration of dye addition. There is therefore considerable dispersion in the upstream and downstream directions over the approximately 3000 ft between stations 2 and 3.

Based on the peak value of 40 fluorescence units at station 3, the dilution factor at this point is 20 to 40 relative to the initial concentration estimate and 1.2 to 12 relative to the fluorescence at station 2. The small tidal channel into which the effluent is discharged meets the main branch of Tide Mill Creek slightly upstream of station 3, so dilution at the high end of this estimated range is likely.

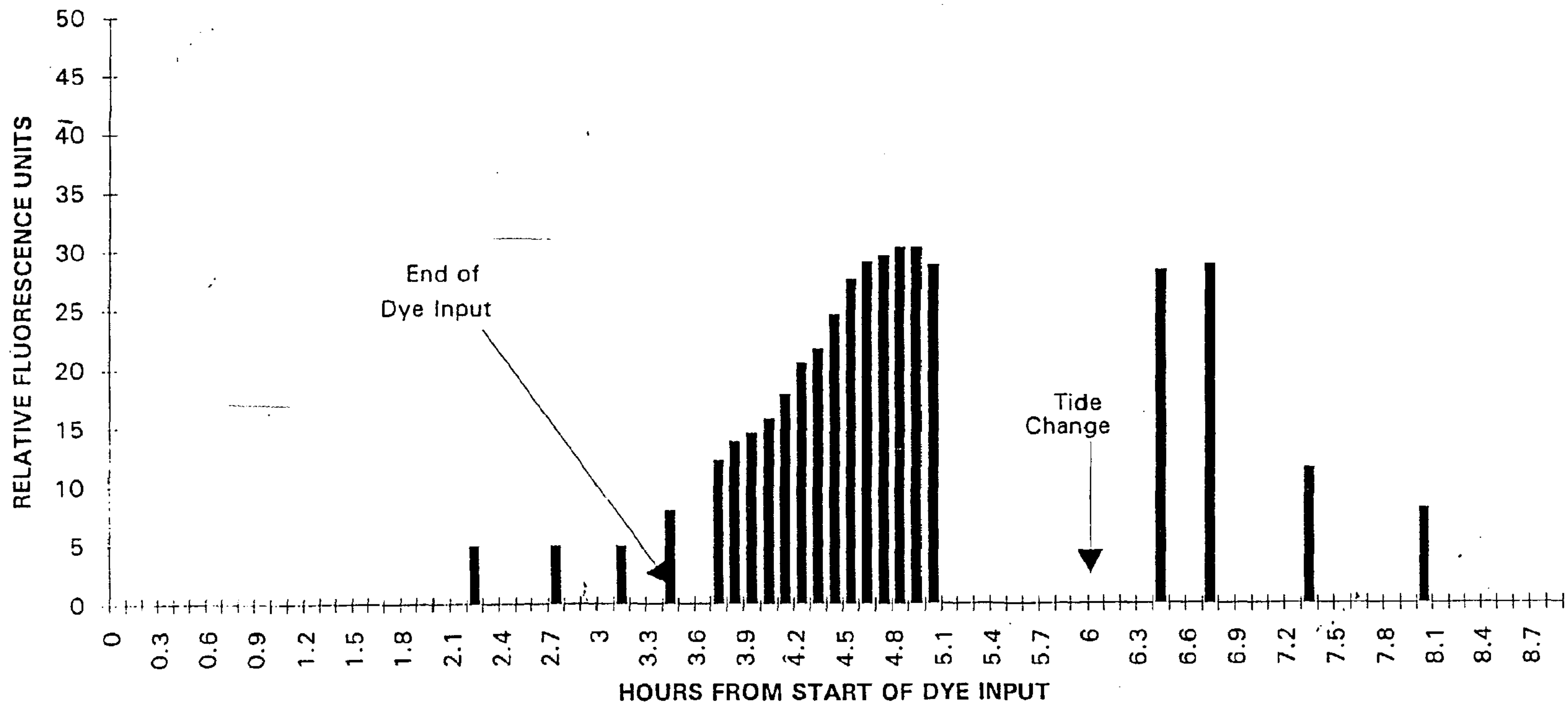
Low tide occurred at about 11:00 AM in the Tide Mill Creek system, and distinct upstream movement was discernible between 11:30 AM and noon. A fluorescence value of 25.3 units was recorded at 12:30 PM at station 3, indicating that the dye pulse was being moved back upstream at that time. A value of 11 units was recorded at station 2 at 1:00 PM, suggesting that only a small portion of the dye was traveling up the tidal creek from which it came. The remainder of the dye passed upstream in the main branch of Tide Mill Creek; dye was visible upstream of the confluence with the tidal channel into which the dye-laden effluent was originally discharged. At 2:00 PM the fluorescence at station 3 was 10 units, indicating substantial dilution of any dye yet to move upstream of that station. Elapsed time from the directional change in water movement was about two hours. Although a portion of the dye pulse remained intact and was pushed upstream, the incoming saltwater appears to provide considerable dilution of the dye plume (up to fourfold at station 3), based on comparison of peak fluorescence values for outgoing and incoming tides.

<u>Activity in lower Tide Mill Creek (Stations 4 & 5)</u>

Dye appeared to reach station 4 at 9:00 AM, and the concentration rose steadily until about 10:00 AM and peaked at 30 units (Table 1, Figure 4). Travel time to this station from the input point was about 3.7 hours and the travel time from station 2 was about 3 hours. Only slight dilution since station 3 is indicated (peak of 40 vs. peak of 30 units). The fluorescence at station 4 remained stable for over 2 hours, spanning the period of low tide and reversal in the direction of water movement. The fluorescence began to decline between noon and 12:30 PM, reaching 11.7 units at 12:36 PM and 8.2 units (background level for the Hampton River) at 1:18 PM. The dye

FIGURE 4

FLUORESCENCE OF RHODAMINE DYE AT STATION 4



pulse never completely passed station 4; the lowest values represent the same water mass moving first downstream and then upstream past this station.

Station 5 exhibited the first signs of fluorescence increase at 9:36 AM, although the first visible range reading occurred at 10:18 AM (Table 1, Figure 5). This represents a travel time from station 1 of 4.3 to 5 hours, and a travel time of 3.6 to 4.3 hours from station 2. Beginning at 10:18 AM, fluorescence levels remained fairly stable at 23 to 27 units for 1.2 hours, after which there was a rapid decline coinciding with the change in tide. Readings were in the background range by noon, an hour after low tide and only a few minutes after discernible upstream water movement occurred. The water mass containing the dye piled up on itself and was pushed back upstream; this process was observable to the naked eye, as dye levels were still in the visible range at this point. Fluorescence remained at the background level for the remainder of the observation period.

Dilution at station 5, the last station before entry into the Hampton River, is on the order of 50 to 100 relative to the initial input level. Dilution since station 2 is by a factor of about 10 to 15. There is additional dilution at the leading and trailing ends of the dye plume during the initial outgoing tide, and even more substantial dilution of a larger portion of the plume with the incoming tide. Some portion of the dye plume remained intact throughout the study period, however, and simply moved up and down Tide Mill Creek. The bulk of the dye plume spanned stations 4 and 5 when the tide changed, and was pushed upstream beyond station 3 by 2:00 PM (high tide occurred after 4:00 PM).

Activity in the Hampton River

For about 1.5 hours around low tide, dye-laden water was able to pass into the Hampton River from Tide Mill Creek. Water velocities were slow at this point, so the actual volume of water leaving the creek and entering the river appeared low. It is roughly estimated that less than 10% of the total dye load exited Tide Mill Creek before the tide changed. Nevertheless, a visible plume was observed along the northern shoreline for about 200 ft from the confluence of the creek and river. The changing tide appears to have caused the dye to hug the shoreline; the trajectory of the dye plume at other tide stages is uncertain.

Fluorescence levels at station 8, the closest downstream station in the Hampton River, were never above 10 units and showed no influence from the dye. Station 8 is part of a three station transect over 500 ft upstream of the closest shellfish beds of interest in this study (Figure 1). There was no evidence of dye reaching these beds during the study period (Table 1, Figure 6). Dye that did enter the Hampton River from Tide Mill Creek was rapidly diluted to background levels and moved upstream with the incoming tide. As the tide changed, the short dye plume in the river dissipated and no dye could be detected either by eye or with the fluorometer. The volume of water moving with the incoming tide simply overwhelmed the small volume of the remnant dye plume, diluting it to background levels. It was windy during the study period,

FIGURE 5

FLUORESCENCE OF RHODAMINE DYE AT STATION 5

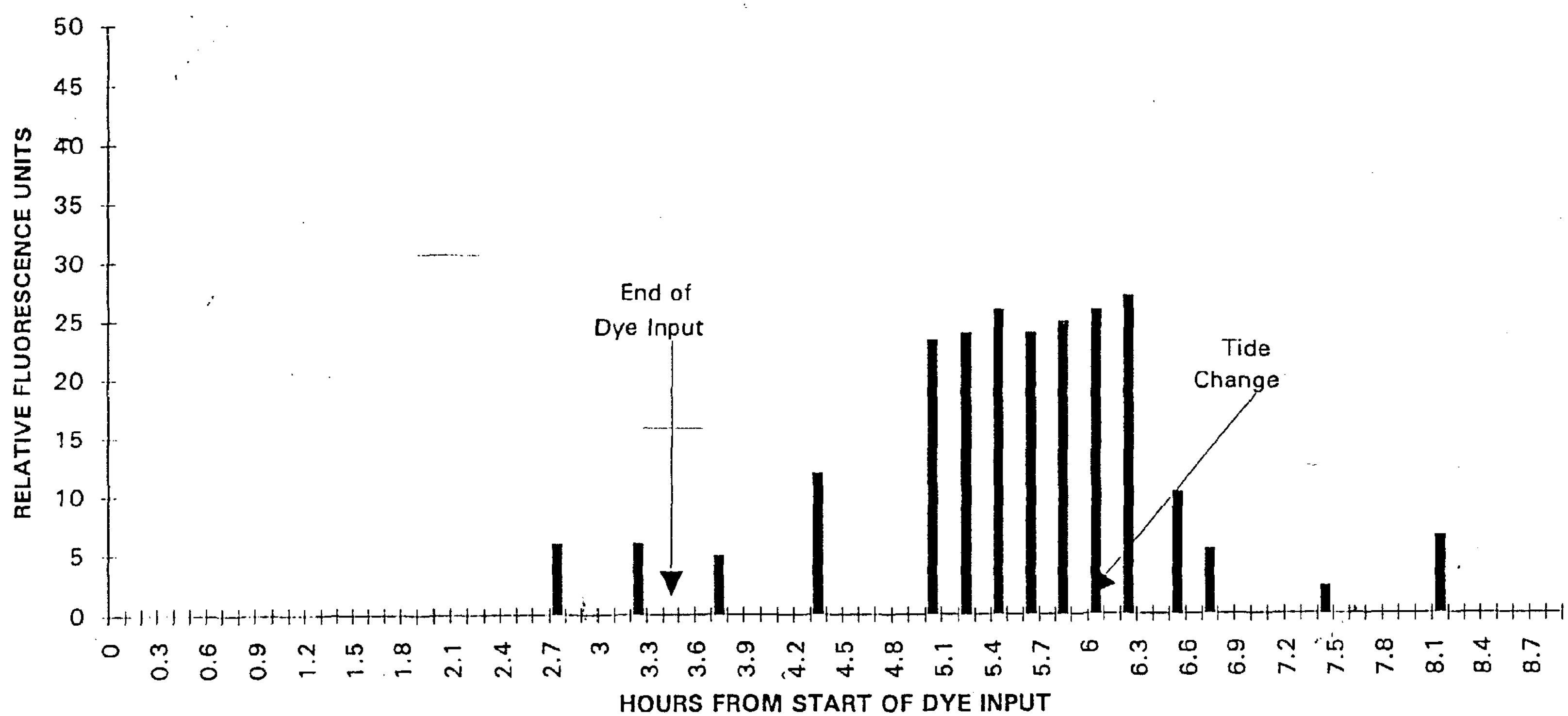


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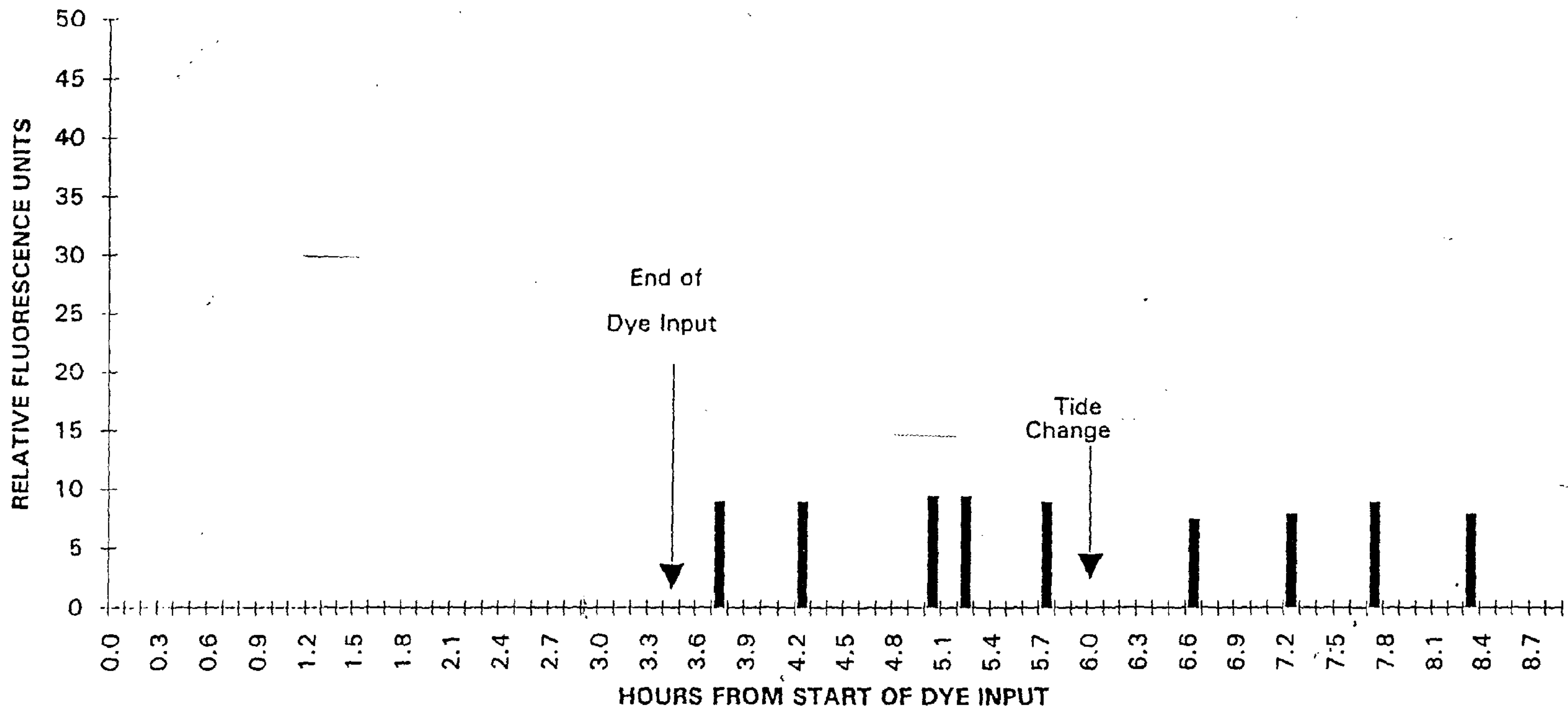
FIGURE 6

FLUORESCENCE OF RHODAMINE DYE AT STATION 8



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which may have aided this mixing process, but the currents created by the change in tide appeared sufficient to create great mixing potential even on the calmest of days.

Discussion:

Travel Time

Based on the results of the dye test conducted on May 27, 1993, pollutants discharged from the Hampton wastewater treatment facility reach the Hampton River in no less than 4.3 hours, and do not reach any significant shellfish beds during the first tidal cycle after discharge. As dye was not actually discharged into the tidal creek until between one half and one hour after high tide due to surcharging of the discharge pipe, it is possible to envision a worst case scenario in which a pulse of dye (or other pollutant) released into the receiving tidal channel at exactly high tide might reach the upstream end of the closest shellfish beds just before the tide changes, pushing the dye (or pollutant) upstream and diluting it extensively. At an absolute minimum, therefore, the time of travel from the wastewater facility outfall to the closest shellfish bed is at least 6 hours under the test conditions. Minimum times of travel for the lead edge of the dye plume and the visible portion of the plume to selected stations are depicted in Figure 7.

The test conditions included a fairly average tidal cycle; lower lows and higher highs are known for Tide Mill Creek. Weather conditions were dry. Had conditions been different, it is not certain that time of travel would have been affected. Additional water at high tide would have resulted in flooding of the non-channel portions of the saltmarsh, possibly impounding portions of the dye plume and slowing complete flushing by several tidal cycles. However, the channelized portion of the dye plume would have been subject to roughly the same velocities, leading to similar estimates of minimum travel time. Had the tide been lower, it is conceivable that the dye might have moved into the lower reaches of Tide Mill Creek somewhat more rapidly, but channel configuration suggests that maximum velocities were rapidly achieved under the test conditions.

For all but an instantaneous discharge at high tide, the travel time to the closest shellfish beds and into the harbor beyond is well over one tidal cycle (approximately 11.5 hours). Discharged pollutants will move upstream and downstream in the Tide Mill Creek system, with each tide change causing further dilution and distribution throughout the associated channels in the saltmarsh. A small portion of the pollutant load would enter the Hampton River each tidal cycle. The longer the duration of discharge, the more tidal cycles it will take for the pollutant to be completely flushed out of the Tide Mill Creek system.

Pollutant Concentrations and Dilution Factors

During the first tidal cycle after an input occurs, that input will be subject to a dilution factor of 50 to 100 in the Tide Mill Creek system and undetermined but substantially greater dilution in the Hampton River. Insufficient data exists to evaluate dilution in the Hampton River, but it would be expected to be at least twice the dilution experienced in the Tide Mill Creek system,

Minimum Time of Travel to Station
from Input Point for:
A) Leading edge of dye plume
(measured as any increase in fluorescence)
B) Stable concentration of dye
(measured as end of sharp increase in fluorescence)

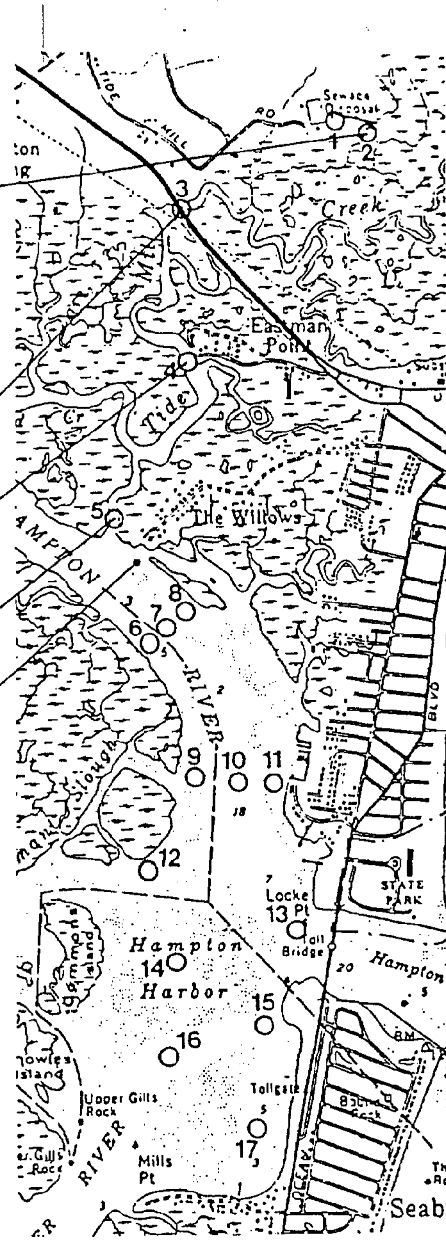
A) 0.7 hr
B) 0.9 hr *
* Extreme tidal volume change caused further increases after this time; also note that travel time declines at lower tide stage

A) 2.2 hr
B) 3.4 hr

A) 3.7 hr
B) 4.5 hr

A) 4.3 hr
B) 5.0 hr

A) 5.5 hr
B) 6.0 hr



Time "A" represents the first possible appearance of dye, no matter how dilute, at the station indicated.
Time "B" represents the leveling off point for fluorescence, indicating the arrivel of the main body of the dye plume.

USGS Hampton, NH 7.5 Min. Series	**Travel Time** Hampton Harbor Dye Study, Wastewater Effluent Time of Travel, Hampton, NH	PREPARED FOR THE NH DEPT. OF PUBLIC HEALTH SERVICES, 6 HAZEN DRIVE CONCORD, NH 03301 June 1993 Job No. 16167999	FIGURE 7 Fugro McClelland

based on a rough estimate of the volume of water between the Tide Mill Creek inlet and the first shellfish beds of interest. Given travel times longer than a tidal cycle, this dilution factor would increase. At a minimum, however, it would be reasonable to expect that any pollutant reaching the shellfish beds from the wastewater treatment facility would be subject to a dilution factor of 10,000 to 20,000 (50 to 100 X 200).

Subsequent to the initial tidal cycle associated with dye or pollutant input, every tidal cycle required to transport a given water mass or pollutant load to the shellfish beds would provide a dilution factor of about 10 at the mouth of Tide Mill Creek. A larger but unknown dilution factor would apply at the closest shellfish bed in the Hampton River. For the dye released in this study, it is estimated that at least 10 tidal cycles would be needed to flush all the dye out of Tide Mill Creek. Given a peak fluorescence of 27 units in the first flush, fluorescence would be expected to decline to the background level (5 to 10 units) after only a few tidal cycles. Based on results at station 3, the length of the visible dye plume was cut by at least half by the incoming tide; there was no major increase in concentration within the remaining portion of the visible plume, so it appears that dilution forces were responsible for the observed change. This further supports the hypothesis that dilution to background levels might be reasonably expected within several tidal cycles.

Beyond a single tidal cycle, dye inputs of the magnitude used in this study would not be detectable in the main body of Hampton Harbor. As it clearly takes more than one tidal cycle for most of a given input to reach the harbor, further transport studies will require dye input at points downstream from the Hampton wastewater treatment facility. Placement of dye at the confluence of Tide Mill Creek and the Hampton River at high tide would be the logical next step in further evaluation of travel time to significant shellfish beds and related dilution factors.

For a continuous discharge such as that of the Hampton wastewater treatment facility, the concentration of pollutants normally found in the effluent (nutrients, BOD, etc.) should acquire a predictable periodicity at any point in the Tide Mill Creek system, with tide stage as the primary determinant of pollutant concentration. Additional variability would be introduced by changes in discharge volume, treatment efficiency, tidal height and removal processes in the tidal system.

With only a change in tidal stage, concentrations would be expected to rise with an outgoing tide and fall with an incoming tide. Concentrations within the path through the saltmarsh to the mouth of Tide Mill Creek would be expected to be the highest ones encountered, but concentrations of any normally discharged pollutant (e.g., nitrogen, phosphorus, suspended solids) would be above pre-discharge background levels throughout the Tide Mill Creek system as a consequence of tidal movements over multiple cycles.

Variability in discharge volume, treatment efficiency and removal on non-conservative substances (e.g., nutrients) in the marsh system will affect ambient concentrations. The greatest potential influence in this regard is wet weather and storm tides, which have several possible effects. Due to infiltration by stormwater runoff and the possibility of major inflows during coastal flooding near sewer line manholes, discharge volume may rise considerably and treatment efficiency will decline during major storms. Flooding of the marshes may enhance uptake potential for contaminants such as nutrients and increase deleterious exposure for toxic substances which might be discharged. Given the sources of dilution water (rain and the ocean), however, the net effect is likely to be an increase in dilution factor for contaminants leaving the Tide Mill Creek system. The exception might be contaminants not normally found in the discharge; flooding of industrial/commercial areas and subsequent drainage into the sanitary sewer line might cause such a phenomenon. Minimization of infiltration/inflow situations is therefore desirable.

One of the forces governing dilution of inputs is dispersion. Without appreciable active mixing, diffusion, channel friction and related forces are expected to lengthen the plume associated with any input over its time of travel through the system. It appears as though the length of the measurable dye plume increased from the original input duration of 3.5 hours to over 4 hours at Station 3. Reversal of flows with the change in tide precludes empirical evaluation of the length of the dye plume further downstream, but the observed increase over just the first 200 ft of travel distance suggests that dispersion is significant.

An Evaluation Framework

Based on the conducted study, it is not possible to conclusively evaluate the passage of dye or other contaminants throughout Hampton Harbor. The failure of the dye to travel to even the first shellfish beds is an important finding, however. The minimum time of travel to the closest shellfish beds is estimated at 6 hours, with little likelihood of that travel time being realized for anything other than a "perfectly" timed discharge. A travel time of more than 11.5 hours is expected for most inputs, with up to 10 tidal cycles (115 hours) estimated to be necessary to completely flush an episodic input from the Tide Mill Creek system. However, inputs may be diluted to non-detectable levels within three tidal cycles.

In terms of evaluating pollutant concentration scenarios, one would compare a target level for a contaminant of interest (e.g., fecal coliform bacteria at 14/100 ml) at the closest shellfish beds with a measured or predicted concentration in the wastewater treatment facility discharge, modified by dilution, uptake, die-off or other mitigating processes over the travel time as suggested by the results of the dye test. Assuming no die-off or other removal of bacteria and a load of 2 million fecal coliform/100 ml at exactly high tide, some portion of this load might possibly reach the shellfish beds in 6 hours, having been diluted by at least a factor of 10,000. This would result in a delivered concentration of 200 fecal coliform/100 ml, well in excess of the standard for shellfish harvest areas. More likely, however, would be a travel time of at least 11.5 hours with a dilution factor of 200,000 and some amount of die-off; this suggests a delivery concentration of less than 10 fecal coliform/100 ml, less than the standard.

The weakest part of this analysis is the travel time and dilution associated with movement in the Hampton River, as the dye barely reached this point during the test period. Additional testing, beginning with addition at the mouth of Tide Mill Creek at high tide, would be necessary to more adequately characterize movement and dilution between that point and shellfish beds of interest. Yet with the information gained through the completed dye study, it is apparent that inputs from the treatment facility are subject to extended travel times and elevated dilution factors which minimize the risk associated with short duration inputs of a potentially deleterious nature.