

TREATMENT OF HAZARDOUS MATERIALS SPILLS IN FLOWING STREAMS WITH FLOATING MASS TRANSFER AGENTS

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(Received April 15, 1975)

Summary

Field studies were conducted in a Flowing Stream Test Facility to determine parameters governing application of floating media (in this case, commercially-available activated carbon) to flowing streams for the purpose of treating hazardous materials spills *in situ*. It was found that removal efficiency is highly dependent on prompt location of the contaminant plume, even dispersion of media over the water surface, and favorable environmental conditions. This technique is most effective for concentrated plumes in small streams, and removal efficiencies increase as the size of the spill increases. Removal efficiencies ranged from 50 to >95%, depending upon the substance being used in the tests.

Further investigation should focus on ballast and packaging techniques, methods for increasing efficiency of contact, prevention of carbon buildup along stream banks, and efficiency of spent carbon collection.

Introduction

The use of floating mass transfer agents for *in situ* treatment of hazardous materials spills has been reported previously [1—3]. For static water bodies, treatment involves introduction of media-containing packages into a contaminated body of water in such a fashion that they sink to the bottom and then slowly release the sorbent media which removes the contaminant as it rises to the water surface. Media containing the sorbed contaminant is subsequently retrieved at the surface.

The prior work involved media development, delivery package development, and field demonstration of the technique. Initial work in the area of media development focused on (1) selection of a commercially available carbon whose controlled wetting kinetics rendered it buoyant, and (2) the formulation of a technique for inclusion of hollow glass microspheres in synthetic resin beads. Appropriate control of ingredients allowed production of buoyant ion exchange resin beads. Subsequent laboratory investigations confirmed the effectiveness of semibuoyant activated carbon and floating ion exchange resins for removing dissolved substances from water.

*Paper presented at the 1974 National Conference on Control of Hazardous Material Spills, San Francisco, Calif., August 25—28, 1974

Parallel efforts were aimed at development of delivery packages for distributing the floating media beneath the spill zone of the static body of water. The packages, containing media and ballast, would sink to the bottom, whereupon the media would be released to rise through the contaminated water to the surface. Three feasible alternatives were identified: containment in weighted plastic bottles, containment in unfired clay containers, and incorporation with gravel ballast in an ice matrix. In the first case, release of the media occurs through the narrow mouth of the bottle. Ballast contained in the bottom of the bottle holds the bottle in an upright position to allow the media to be released. Release of the media from the other packages occurs upon disintegration of the clay container in water or melting of the ice cake. All three delivery packages are considered potential alternatives at the present time.

Field demonstration was conducted using activated carbon contained in weighted plastic bottles. A total of 845 lb. of carbon was applied to a simulated spill of 78 lb. of an emulsifiable oil solution of an organophosphate pesticide in a 10 million-gal water storage basin. The bottles of carbon and ballast were dropped into the spill area from a helicopter. Carbon was subsequently collected at the surface through use of an oil-containment boom and pumped as a slurry to a storage tank. Analysis of pre-treatment and post-treatment water samples taken in the spill zone showed that approximately 80% of the pesticide was removed from the water.

The need for methods of effectively dealing with hazardous material spills in flowing streams is equally as great as that for static waters as evidenced by the large number of spills that occur in rivers and streams. Consequently, the work reported herein was undertaken to focus on application of floating media in general, and floating activated carbon in particular, to flowing streams. Important issues to be addressed included the need (or lack thereof) for ballast and packaging, the efficiency of contact, probability of unsightly carbon buildup along stream banks, and the efficiency of spent carbon collection.

The test facility

All tests were conducted in the Flowing Stream Test Facility (FSTF) which is an abandoned irrigation canal located on the Atomic Energy Commission Reservation at Hanford, Washington. The partially cement-lined canal was taken out of operation some thirty-four years ago when the federal government appropriated the land. Since 1973, however, it has been the subject of renovation efforts aimed at equipping it for use as a model stream for hazardous materials spill research.

For purposes of this program, renovation largely consisted of efforts to provide and control the flow of water. A nearby well was deepened, reactivated, and fitted with a gasoline-driven pump capable of producing 200 gal of water a minute. Water was carried by aluminum irrigation pipe to a reservoir formed in the upper 1000 feet of the canal by a permanent weir with a

screw-controlled drop gate. This section is followed by 2200 ft of test run and an additional 200 ft of quiescent water. The test section of the canal has a trapezoidal cross-section with a 5-ft base, a 15-ft top, and a 5-ft altitude with a slope of 0.00024. The quiescent section was widened to approximate a 20 × 5-ft rectangular cross-section. Flow here is controlled by a second weir with an optional overflow or underflow gate. After passage through the second weir, the water is released to a sandy basin in the adjoining desert, where it quickly seeps into the ground. During actual field studies, the flow is produced by combining the reservoir water with the pump discharge. Total flows of 0–10 ft³/s can be achieved. An average velocity of 1.0 ft/s can be attained at a flow depth of 1.5 ft. A schematic diagram of the test facility appears in Fig. 1.

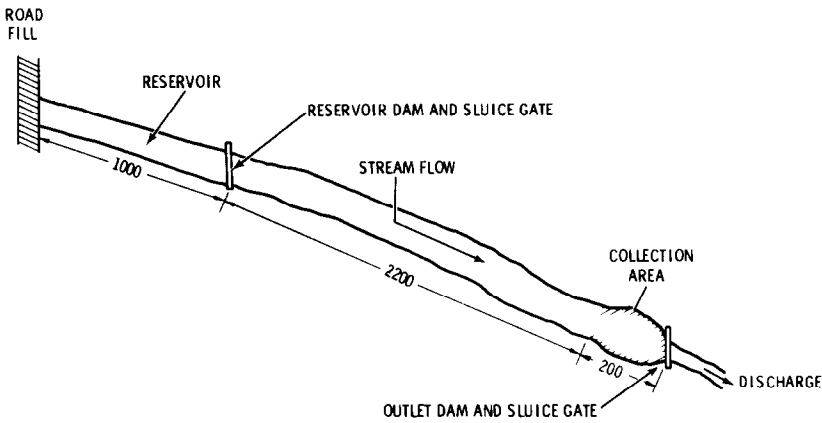


Fig 1 Test section of canal

Since the integrity of the original cement lining was breached by various plant forms, temporary linings were installed in portions of the canal for the present program. The reservoir and the quiescent section were lined with heavy-duty polyethylene sheeting. Individual sheets were sealed together and covered with soil and gravel to prevent wind damage. The test section was treated with a slurry of bentonite clay to seal off major infiltration routes. Figures 2–6 illustrate various features of the canal during a recent test run.

A collection boom was constructed in the quiescent section for retrieval of the floating media. The boom was formed by sections of 2 × 4's strung on a nylon rope. A plastic skirt was attached to each segment such that it extended 3 in. into the water and 3 in. above. Media was pumped from the front of the boom with a gasoline-operated diaphragm pump. The collection port was funnel-shaped and sat just below the water surface in front of the boom. Holding tanks were maintained for drying and weighing retrieved media.

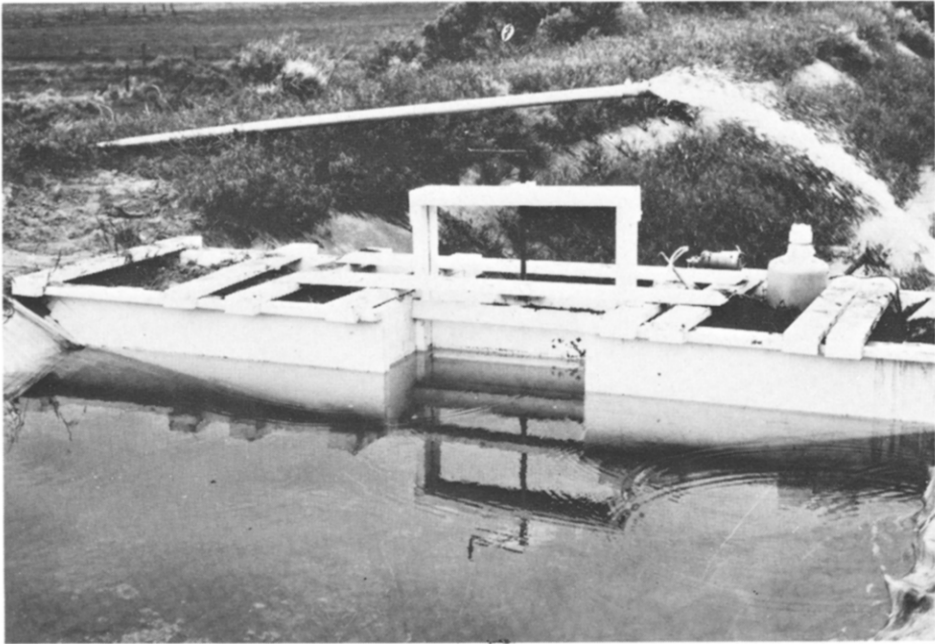


Fig 2 Reservoir section of Flowing Stream Test Facility (FSTF) looking downstream

System dynamics

Major problems are associated with the application of packaged media to flowing streams. As a result of movement of the contaminated plume with the current, timing of media release becomes critical. If media were delivered in packages, the release of the media from the packages would have to be timed exactly to coincide with the passage of the plume in order to achieve effective treatment. In order to avoid this problem, two alternative methods of application were explored: (1) surface application of the media with contact dependent upon the natural turnover of the stream water, and (2) subsurface injection of slurried media.

Surface application relies on two mechanisms to provide intimate contact between the contaminated water and the buoyant sorption media. Both of these are related to the natural turnover of the water as it flows downstream. The first mechanism involves the vertical velocity components of the flow itself, which disperse fine media particles downward where they contact contaminated waters and sorb the contaminant. In the case of the second mechanism, the larger particles float on the surface and sorb contaminant from the deeper waters as the latter come to the surface and roll back to the bottom. The two mechanisms are conceptualized in Fig.7.

With subsurface application, the media is slurried and pumped into the deeper portions of the contaminant plume. Intimate contact is achieved



Fig 3 Test section of FSTF looking downstream



Fig 4 Test section of FSTF looking upstream toward reservoir



Fig 5 Quiescent section of FSTF looking downstream

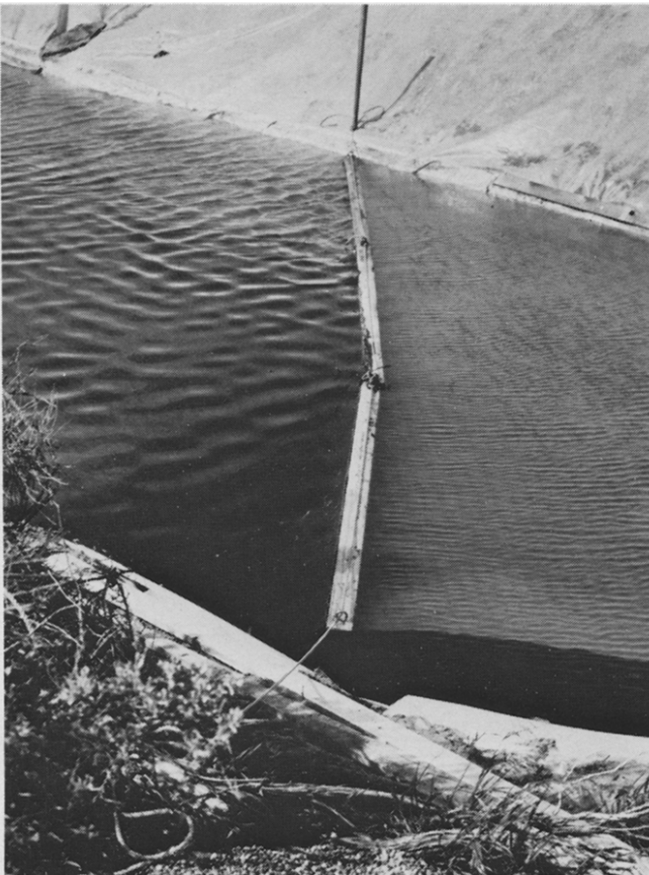


Fig 6 Booming floating carbon in quiescent section of FSTF

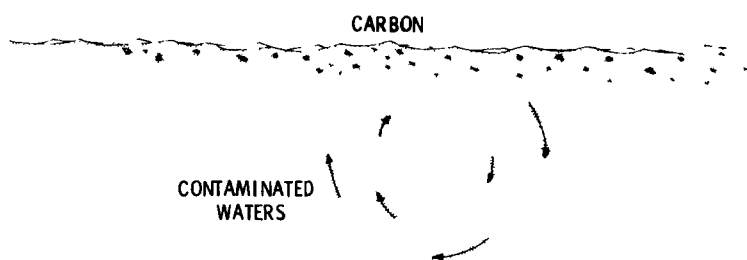
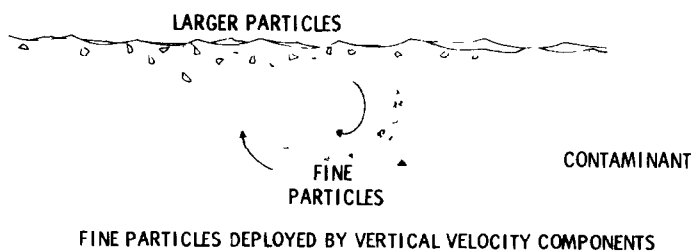


Fig 7 Mechanisms for removal of contaminants by surface-applied floating mass transfer agents

initially through the dispersion of the media slurry itself in the receiving waters and its subsequent ascent to the surface.

Optimal media particle size will depend in part on the mode of application anticipated. Since surface collection of spent media in quiescent reaches is the mode of retrieval, particles must be sufficiently buoyant (a function of particle diameter when density is held constant) to rise to the surface during residence in the selected quiescent zone. On the other hand, if particles are too large they will not be carried down into the water column or will rise too quickly after subsurface injection to achieve the required contact. These system requirements therefore determine physical limitations on the acceptable particle size range for buoyant sorption media. They, in turn, are influenced by the velocity components of the receiving waters.

Field studies were conducted to determine the approximate mesh ranges of Nuchar C-190[®] which would rise to the surface when applied to flowing streams. All samples greater than 250 mesh were found to be sufficiently buoyant to be recovered in quiet waters. The breakpoint for large particle sizes was more difficult to define. Whereas carbon in the size range greater than 50 mesh was found to stay on the surface with no mixing under calm conditions, a slight wind was sufficient to ripple the surface and initiate move-

[®] Registered trademark for a floating activated carbon produced by the Westvaco Company

ment of the particles into the water column. To facilitate testing, selection was oriented to assure all particles could be recovered on the surface and many would mix under varying environmental conditions. For practical purposes, the optimal working range was defined as 50 × 250 mesh. While this includes many large particles which may never mix to a significant degree, it will be far less costly to obtain commercially than a narrow size range.

Field studies

Field studies were conducted in the Flowing Stream Test Facility at flow rates ranging from 3.98 to 4.45 ft³/s. Spills were simulated with a solution of 1816 g methylisobutyl ketone (hexone), 550 g of methanol, and 45 g of rhodamine dye. The methanol was employed as a wetting agent to enhance the solubility of the dye and the hexone.

Three series of tests, each composed of multiple runs, were carried out during the course of the program. Each series differed in the manner in which the spill was simulated and in which the contaminant plume was allowed to develop prior to treatment. In addition, carbon mesh size was varied for certain of the test series.

For each series of tests, a spill was conducted without application of floating media to establish background levels for the contaminant plume and the effects of natural dilution. This was necessary, for, in addition to dilution, sorption onto plants and material in the test canal occurred during the course of the study. Removal was then defined as the difference between concentrations for treated and untreated samples taken at the same location. For the first series of tests, the hexone solution was spilled over a 10-s period at a point 200 ft downstream of the reservoir. This location was selected to assure that all artificial turbulence from the sluice gate was damped. Forty pounds of floating carbon was applied to the stream at a point 230 yards from the reservoir (approximately 10-min flow time). Large grain size (12 × 40 mesh) Nuchar C-190 was employed for all tests. Runs involving both surface and subsurface application were conducted in this series. Surface application consisted of sprinkling the carbon on the water as the contaminant plume reached the application point. For the subsurface application case, a carbon slurry of approximately 10 g/l was prepared prior to the spill and was then pumped to the bottom of the stream as the contaminant plume passed.

Three sets of samples were taken during the trials. The first, at sample site S, was taken just upstream of the carbon application site. The second, at sample site C, was taken at the head end of the quiescent reach (approximately 15–25 minutes of carbon contact time). Sample site D was located at the lower end of the quiescent reach just behind the carbon collection boom. Samples at this site may not be completely representative since the 20-ft channel width and unpredictable currents make it difficult to obtain composite samples. Figure 8 is a schematic diagram showing the locations of the sampling points.

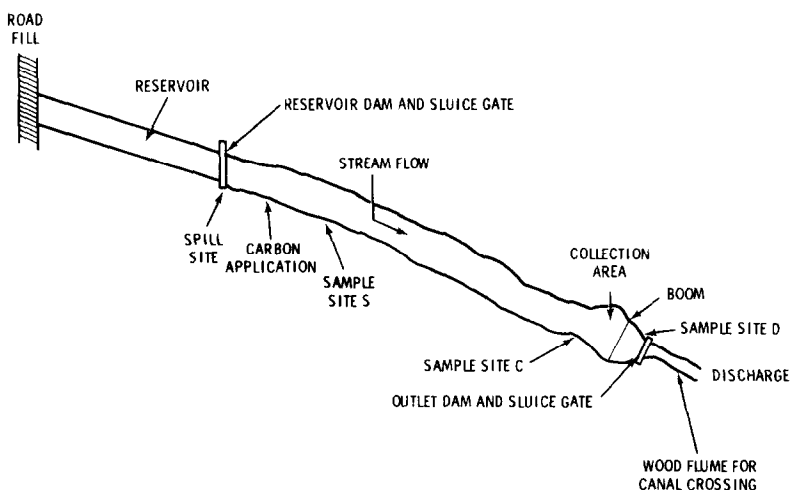


Fig 8 Sampling site locations for test series No 1

Three analytical techniques were initially employed to characterize the spill. Dye content was measured using a GK Turner Model 111 fluorometer. Total organic carbon content was monitored through use of a Beckman Model 915 total organic carbon analyzer. Hexone measurements were made with a Perkin—Elmer 900 gas chromatograph

Results of hexone, rhodamine dye, and total organic carbon analyses are presented in Table 1. The total material figures were derived from concentration measurements taken at specified time intervals as the plume passed the

TABLE 1

Analysis of series of No 1 spill plumes

	Run No 1 Blank 6761 l/min (3 98 ft ³ /s)	Run No 2 Subsurface slurry application 9173 l/min (4 45 ft ³ /s)	Run No 3 Surface application 9173 l/min (4 45 ft ³ /s)
Sample Site S			
Total Hexone (g)	616	481	589
Total Organic Carbon (g)	887	591	587
Total Dye (g)	44 0	38 1	34 9
Sample Site C			
Total Hexone (g)	670	643	508
Total Organic Carbon (g)	872	559	751
Total Dye (g)	37	10 0	1 5
Sample Site D			
Total Hexone (g)	752	223	341
Total Organic Carbon (g)	737	271	574
Total Dye (g)	26 7	1 4	0 76

sampling point and summed for the plume at the flow rate noted. Samples were taken across the entire width of the stream at a depth of 6 in., with some provision for a larger sample input at the deeper center portion of the flow. All samples were stored in glass bottles and refrigerated until analysis.

The apparent fractions remaining in Runs 2 and 3 as compared to the blank Run 1 are given in Table 2. Table 3 shows the apparent fractions remaining when compared to the initial samples at site S. Several observations are in order.

It is evident from the data that a large fraction of the hexone cannot be accounted for. Only 26–34% of the original 1816 g of hexone was detected

TABLE 2

Test Series No 1
Apparent fraction remaining compared to blank run No 1

	Run No 1	Run No 2	Run No 3
Sample Site S			
Hexone	1 00	0 78	0 95
Organic Carbon	1 00	0 86	0 86
Dye	1 00	0 86	0 79
Sample Site C			
Hexone	1 00	0 96	0 76
Organic Carbon	1 00	0 64	0 86
Dye	1 00	0 27	0 04
Sample Site D			
Hexone	1 00	0 30	0 45
Organic Carbon	1 00	0 37	0 78
Dye	1 00	0 05	0 02

TABLE 3

Test Series No 1
Apparent fraction remaining compared to initial sample S

	Run No 1	Run No 2	Run No 3
Sample S			
Hexone	1 00	1 00	1 00
Organic Carbon	1 00	1 00	1 00
Dye	1 00	1 00	1 00
Sample C			
Hexone	1 08	1 34	0 86
Organic Carbon	1 27	0 94	1 28
Dye	0 84	0 26	0 04
Sample D			
Hexone	1 22	0 46	0 58
Organic Carbon	1 07	0 46	0 76
Dye	0 61	0 04	0 02

in the initial, untreated S samples. Similarly, only 39–45% of the original TOC was detected at site S, while virtually all of the dye was accounted for. The data suggest that the apparent loss in TOC can be attributed almost entirely to the apparent hexone loss. At site S, the loss in hexone, 1200–1535 g, translates into a theoretical TOC loss of 864–1052 g as compared to a measured TOC loss of 826–926 g.

Since methanol is more volatile than hexone and apparently little methanol is unaccounted for, evaporation does not appear to be a plausible explanation of the apparent loss. A more reasonable explanation is that the dye and the methanol are both water-soluble to a greater extent than hexone and hence can be expected to mix quickly. This is particularly true for the methanol, which in turn will carry dissolved rhodamine with it. The hexone, on the other hand, mixes slowly and appears to form a lighter floating layer of hexone and hexone-saturated water solution. There would then be a gradient from high hexone concentrations at the surface to lower concentrations with depth below the surface. Hence, samples taken at a 6-in depth may underestimate hexone content considerably. If this incomplete mixing hypothesis is true, it would explain the apparent production of hexone in the blank run as the plume moved downstream. That is, with movement downstream, turnover and vertical dispersive forces would slowly bring the hexone to an iso-concentration state thus raising the amount of hexone at the 6-in depth level. This would be especially true of the D samples, since the collection boom would stimulate vertical currents.

Stratification of this nature could well affect removal efficiency. Whereas the apparent removals were 64 and 45% hexone, respectively, more than half of the original spill was on the surface of the flow where the bulk of the carbon remained. Hence, all of the missing hexone may well have been sorbed on the carbon by the end of the run. Removal of dye was consistently better than 90%. This does not allow for corrections required as a result of differences in absorption onto plants and soil in the treated runs as compared to the blank run, but there is no reason to believe such a correction would be very large.

There appears to be no advantage in using slurry application over surface application with the larger grain size carbon. This may in part be an artifact of the mode in which the slurry was pumped into the ditch, but more likely it reflects the quick rise time for the large particles and hence a minimal amount of increased contact with submerged waters. The advantages of sub-surface injection are likely to become apparent in deeper streams where surface application leads to contact with only a portion of the contaminated plume.

Comparison of TOC, hexone, and dye levels reveals no constant relation between any two parameters. This might be expected since the three components vary in their solubility, tendency to stratify, and adsorptive properties. The use of gas chromatography for hexone detection proved very satisfactory with good reproducibility on field samples and standards. Therefore, since

hexone was the major component of the spill, hexone analysis was selected as the major measurement basis in subsequent trials. TOC and dye measurements were used sparingly to provide confirmation on hexone data.

During the first series of runs, several environmental factors were found to complicate spill response activities. It was found that wind conditions greatly influenced the effective contact time achieved during any single run. The larger, more buoyant, carbon particles stayed at, or very near, the surface throughout the test period. Wind moving in the direction of the flow accelerated the floating media to a velocity much greater than that of the spill plume itself. Thus, after a short contact period, the carbon passed the contaminant plume and moved downstream in contact with relatively unaffected waters. Under calm conditions, a similar development was observed to occur over a longer period of time as a result of the greater relative velocity of the surface waters to that of the deeper layers. Conversely, when winds prevailed in a direction counter to flow, the carbon stayed with the contaminant plume throughout the test period.

Difficulties were also experienced in collecting the spent carbon. The carbon was easily detained behind a wooden boom fitted with plastic skirts. When an attempt was made to pump the contained carbon to a holding facility, however, it was found that abundant plant debris quickly plugged the lines. The debris was excessive as a result of the intermittent flow pattern in the test facility. During dry periods, various wind-blown plant forms accumulated in the run stretch. Initiation of flow then scoured these weeds throughout the 2–3 hour test period. This should not prove to be a major problem in natural streams if flooding is not occurring. Additionally, coarse screens preceding the intake line were found to remove most of the plant debris and thus enable collection of the carbon.

The second and third test series were performed over the full length of the facility. For the first of the two series, the dye–hexone–methanol solution was added to the turbulent waters at the foot of the reservoir weir with a variable speed pump over a 5-min time period. The pumping rate was adjusted to simulate the concentration gradient observed in well-developed plumes. Carbon addition was carried out a short distance downstream from the simulated spill. Hence, carbon contact time prior to booming in this series of runs was substantially longer than in previously reported runs. The locations of the application point and sampling sites are indicated in Fig. 9.

Results of runs conducted in this manner are presented in Table 4. The coarse carbon employed was the standard 12×40 mesh Nuchar C-190 applied in previous tests. The fine carbon was 60×230 mesh Nuchar C-190. Each test involved the use of 40 lb of carbon and 4 lb of hexone as in previous trials.

From the data of Table 4, it can be seen that subsurface slurry addition of the coarse carbon was not as efficient as surface application of the coarse or fine carbons. The fine carbon effected a better overall removal than the coarse carbon. It is interesting to note that removal declined with travel down the

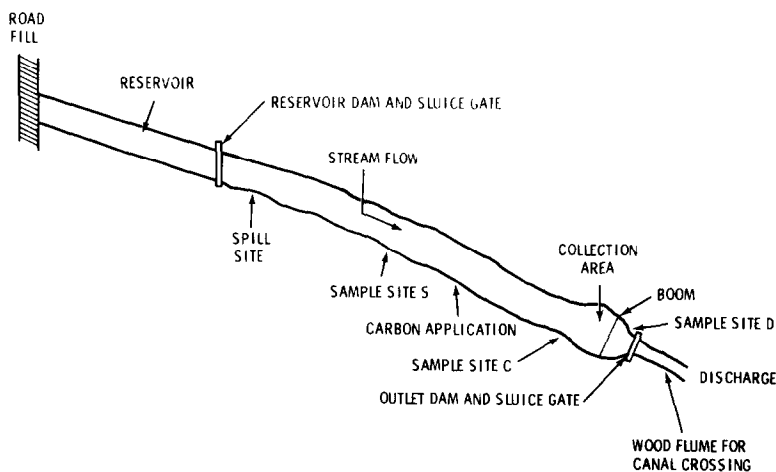


Fig 9 Sampling site locations for test series Nos 2 and 3

canal. This is thought to be a result of desorption as loaded carbon traveled past the contaminant plume and became exposed to “uncontaminated” waters. Subsequent work in the laboratory revealed that desorption does indeed occur. This will not be the case with all hazardous substances, since some have very shallow sorption isotherm slopes, and others undergo irreversible adsorption.

Desorption apparently did not occur in prior runs because of the shorter distance traveled and the stratification of the hexone. Had the last test series been terminated at sample point S, removal would have been comparable with that reported for the prior runs. It is also interesting to note that much more hexone is accounted for at all sample sites than in test series 1 or 3. This further substantiates that better mixing was achieved when the hexone was pumped into the water column, and therefore samples taken at depth were representative of the plume.

Samples of spent carbon were collected at sample site D. These were subsequently eluted with four methanol rinses to desorb hexone. (Previous laboratory work indicated > 95% recovery can be achieved with a series of four methanol washes.) The methanol was then analyzed with the gas chromatograph to determine the total hexone contained in the 40 lb. of carbon applied to the spill. This input then was added to the quantity measured in the water to complete a material balance on the hexone. Recovery was typically 74–78%, except for Run 2 where an extraordinary 99.7% was accounted for. This figure is believed to reflect a non-representative sample of carbon.

The third series of runs was performed to evaluate instantaneous spill application. For this series, the dye–hexone–methanol solution was spilled instantaneously (duration ~10 seconds) at the reservoir weir. Carbon application and sample sites remained the same and can be seen in Fig 9. Forty-eight

TABLE 4

Test Series No. 2
Results of runs with spills in turbulent section of the flowing reach

Run No	Description of run	Hexone at sample site S (total g)	Percent remaining run/background	Hexone at sample site C (total g)	Percent remaining run/background	Hexone at sample site D (total g)	Percent remaining run/background	Hexone on carbon (total g)	Percent hexone accounted for at site D Σ total/1816 g
1	Background	1986	100	1650	100	1408	100	—	78.0
2	Slurry addition of coarse carbon	1618	81	1222	74	1592	113	219	99.7
3	Surface addition of coarse carbon	925	47	1186	72	1242	88	162	77.3
4	Surface addition of fine carbon	987	50	1201	73	1170	83	185	74.6

TABLE 5

Test Series No. 3
Results of instantaneous spill conducted at reservoir weir

Run No	Description of run	Hexone at sample site S (total g)	Percent remaining run/background	Hexone at sample site C (total g)	Percent remaining run/background	Hexone at sample site D (total g)	Percent remaining run/background	Hexone on carbon (total g)	Percent hexone accounted for at site D Σ total/1816 g
1	Background	794	100	1364	100	1418	100	—	78
2	Forty-eight pounds fine carbon applied at surface	714	90	1045	77	722	51	118	46

pounds of fine carbon (60 × 230 mesh Nuchar C-190) was then spread on the surface. Results of this application are presented in Table 5. It would appear that hexone stratification again occurred. As in test series 1, the recovery of hexone at sample site S during the background run is quite low. This suggests that it was not the turbulence at the weir that eliminated stratification in the second test series so much as the means of introducing the hexone to the water. In the earlier series, when the hexone was pumped into the water the discharge end of the hose was placed down into the water column. This apparently created much better mixing and minimized the effects of stratification. The removal obtained in the final test is comparable with that noted in the shorter runs of test series 1. Removal clearly is enhanced with stratification. This no doubt reflects the greater contact between the carbon and the concentrated portion of the hexone plume at the surface. The poor recovery of hexone in the material balance is similar to results obtained in test series 2.

Samples of carbon were taken at each sampling site to investigate desorption. The total hexone accounted for as on the carbon was 0.67 g, 135 g, and 118 g for sites S, C, and D, respectively. Some desorption appears to have occurred, but the effect was generally overwhelmed by the effects of stratification. Desorption in this case may be the result of either passage back into the water column or volatilization to the atmosphere. Some degree of the latter would tend to explain the poor material balance results. The potential for volatilization from the carbon is greater than that from the water itself since the black carbon absorbs a great deal of solar radiation and thus heats the hexone directly. In this respect, the carbon may act as a pump withdrawing hexone from the water and releasing it to the atmosphere.

During the various test runs, it was noted that carbon loss along the sides of the stream was not significant. Carbon recovery with the booming system, on the other hand, was very effective with in excess of 90% of both the fine and the coarse carbon accounted for.

Practical aspects of *in situ* treatment in flowing streams

Field trials have shown that floating sorbents can be effective in removing organic materials spilled into flowing streams. Removal, however, is highly dependent upon the prompt location of the contaminant plume, even dispersion of media over the surface, and favorable environmental conditions. The difficulties observed during this well-controlled testing program suggest that efforts should be restricted to small streams and then only in response to spills characterized by relatively concentrated contaminant plumes.

Wind will prove to be one of the major obstacles to efficient use of floating media. Not only will air movement result in significant effects on the contact period, it can severely hamper collection efforts by herding the media away from the boom. If aerial application is attempted, wind complications will be further amplified.

Use of floating media also carries the potential for leaving unsightly carbon residuals along shorelines and beaches. While these effects were minimal during field trials, they must be considered prior to application in any public waterway.

The studies made to date suggest that removal efficiency will be greatly affected by scale. Small spills such as those employed in the test program amplify the sensitivity to dosing and environmental considerations. Larger spills are marked by much larger spill plumes and higher concentrations. The dilute edges of the plume represent a much smaller percentage of the total spill. Therefore, removal in the center of the plume where the carbon is most efficient and where movement of the carbon does not separate it from the contaminated water is a greater part of the total removal. This in effect means that average removal is likely to be much better on a larger scale than that noted in the field studies. This scale effect was noted in static water testing. A small acid spill in a semi-confined basin revealed very poor removal when compared to laboratory work. A much larger pesticide spill, however, resulted in removals comparable to those obtained in confined column work in the laboratory. The edge and dilution effects become very important as scale is reduced, and subsequently removal suffers in small scale applications.

It has been noted that the hexone employed in the testing program to date has a tendency to stratify when released in water and, in so doing, complicates sampling. Volatility and reversible absorption characteristics add to the uncertainty of analytical results. While these properties make hexone a difficult material to study carefully, it must be realized that they are properties shared by many hazardous substances and hence reflect real problems encountered in the field. Thus the data is complicated by incomplete recovery of all material and the necessity to look at apparent removal as opposed to absolute removal. The rhodamine dye, on the other hand, represents a conservative substance. It mixes well in the water, it undergoes no rapid degradation or volatilization, and it absorbs onto the carbon with little apparent desorption. Removal is consequently much better for this substance (>95% versus 50%). Many hazardous substances will behave as the rhodamine dye when spilled and will therefore show much higher apparent removal efficiencies.

Acknowledgment

This work was funded by the U.S. Environmental Protection Agency, Hudson-Delaware Basins Office, Edison, N.J., under Contract No. 68-03-0330.

References

1. A. J. Shuckrow, B. W. Mercer and G. W. Dawson, The application of sorption processes for *in situ* treatment of hazardous material spills, Proc. 1972 Natl. Conf. on Control of Hazardous Material Spills, Houston, Texas, March 21-23, 1972.

- 2 B W Mercer, A J Shuckrow and G W Dawson, Treatment of hazardous material spills with floating mass transfer media, U S Environmental Protection Agency, EPA-670/2-73-078, 1973
- 3 B W Mercer, A J Shuckrow and G W Dawson, Application of floating mass transfer media to treatment of hazardous material spills, 46th Ann Water Pollution Control Fed Conf , Cleveland, Ohio, October 4, 1973