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Description and Calibration Results of an In-Situ Suspended Matter Sampler - The McLane Water Transfer System

By

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ABSTRACT

The McLane Water Transfer System (WTS) is an programmable remotely operating insitu instrument designed to collect particles suspended in seawater onto discrete filters at a selectable time interval and in response to storm events as identified using a transmissometer.

Laboratory tests indicate that the standard manufacturer's spring loaded check valve sampling tip appears to be inappropriate in areas where sand sized particles are in suspension. Compared to more satisfactory through-hole sampling tip, the check value tips prefilter up to 20 percent of coarser sized particles.

A quality control and pre-deployment testing program of the WTS units at a dock facility is described. Comparisons of total suspended matter (tsm) weights collected by the WTS instruments are compared with those collected from a standard oceanographic suspended matter collection device (niskin bottle) under varying tidal flow conditions. During slack tide, the correlation coefficient (A2) of results by the two methods was 0943. Coefficient was 0.54, dictating that all calibrations should be conducted at slack tide.

A volume comparison of water filtered as calculated by the computer algorithm with that actually collected at the exit port of the WTS units indicates no statistical difference between the two volumes. This implies that the volume electronically calculated by the WTS computer can be confidently utilized to calculate corrected tsm values (mg/L) the data is

downloaded upon recovery, from the field.

The WTS system determines volume of seawater filtered by counting the rotations of the displacement pump. Field tests of this method confirmed accuracy of +6%.

INTRODUCTION

The U.S. Geological Survey (USGS) in Woods Hole, MA is currently conducting oceanographic monitoring studies near the proposed sewage outfall site in Massachusetts Bay slated to come on line in 1997 (figure 1, Bothner and others, 1994). One aspect of this study is to determine the concentration of suspended particulate matter during different seasons and particularly during major storm events when sampling from a ship is impossible. Information on the concentration of particulates and the processes by which they are transported is critical to understanding the fate of pollutants because many pollutants in the coastal ocean are absorbed by and transported with suspended particulate matter. The data generated in this overall study will allow a comparison of suspended matter concentration and composition before and after the new outfall for Boston's sewage effluent comes on line.

The objective of this report is to describe the insitu instrumentation used to collect suspended material and document the calibration procedures used before and after each mooring deployment.

Background

A number of suspended matter collection devices have evolved over the years. Yentsch (1962) used a hose and shipboard filtration unit to obtain samples from depths to 50 meters. Laird et al. (1967) developed a surface powered unit to collect from depths to 200 meters. Spencer and Sacks (1970) used a self-contained pump deployed from a wire to sample from depths as great as 5700 meters. In-situ devices of varying levels of sophistication have been developed for the measurement of primary production (Gunderson, 1973; Billington and Fair 1984). Short term, high resolution near-surface instrumentation for measurement of phytoplankton production has been developed by Taylor et. al., 1983, Lohrenz, et. al., 1987, and a programmable unit by Taylor and Doherty, 1990.

Large aperture programmable time-series sediment traps which advance collection vessels on an timed basis are used to collect suspended sediment throughout the water column have been developed by Baker and Milburn (1983) and Honjo and Doherty, (1988).

DESIGN

A state of the art suspended sediment sampling instrument, the McLane AT-WTS (Action Triggered Water Transfer System) Mark 5-18, has been developed by McLane Research Laboratory in Monument Beach, Massachusetts. This interactive programmable instrument is designed to collect eighteen suspended sediment samples either on a timed schedule or in response to an external signal. It operates in water depths of up to 5000 meters. In our application, it is connected to a transmissometer, which optically senses the concentration of suspended matter in the water column and when a threshold transmission is exceeded the filtration cycle is triggered.

The At-WTS is comprised of three main components: 1) the controller housing, 2) the pump assembly, and 3) the frame (figure 2). The controller housing contains a McLane ITC-6FM tattletale computer with 0.5 MB memory, an interface board, which allows for external programming and data extraction by a personal computer, a three-phase motor board for driving the stepper motor in the pump assembly, and internal batteries for powering the unit. The pump assembly contains eighteen forty-seven millimeter diameter filter holders, a three-phase brushless DC motor which drives the positioning valve, a graphite gear pump which pumps the seawater, external vacuum tubing, and manifold assembly. The frame is constructed of 3-16 stainless steel and can be linked directly into sub-surface oceanographic tethered or fixed mooring arrays.

The AT-WTS software is written in tattletale basic language. The software is menu driven and allows the user to run configuration files, diagnostics, and post-run data extraction files. Through the software, the user can select a wide range of control settings to adjust the instrument's function to expected conditions. For example, the user can select pump flow rates, total volume to be pumped, use of optical sensor to trigger pumping, threshold for optical sensor, and number of optically triggered events (storms) to sample (McLane user Manual, 1992). Communication is done through an MS-DOS compatible computer using a standard RS-232 serial interface port with a cable connection on the controller housing.

In our application, sampling is done on both a time lapse basis and from an external signal from a transmissometer. When a sampling event is initiated the positive displacement pump draws ambient sea water through one of 18 filter holders located upstream of the pump. The particles are retained on the filter while the water passes out an exit port at the rear of the pump motor. As pumping and loading of the particulates onto the filter continues, the software senses an increasing back pressure on the filter and decreases the flow rate in a step wise manner. When the pre-programmed minimum flow rate or selected volume is achieved, the computer shuts off the pump and activates the stepper motor to sequence the internal valve to the next filter holder. The internal computer records the flow rates, total volume pumped, motor speeds and transmission valves and stores them to memory for retrieval upon instrument recovery.

If the AT-WTS is connected to a transmissometer, the normal sampling interval based on time is interrupted during sediment resuspension events. For example, when a storm passes and resuspends material into the water column, the optical clarity of the water decreases as measured by decreasing voltage from the transmissometer. If the voltage declines below the pre-determined threshold setting corresponding to the beginning of the storm , a pump event is initiated. Two additional sampling events follow which correspond to the middle and end of the storm as determined by a computer algorithm which analyses the transmission voltages over time. The program estimates the storm midpoint or maximum turbidity in the following manner. The program updates and records the N most recent transmissometer readings where N is the number of summed transmissometer intervals entered in the pre-programming option, typically 128, equivalent to 8 hours of data. To determine if a storm has peaked, the N1 to N64 oldest values ("O") are averaged and compared to the N65 to N128 most recent values (R). R is greater than O when the storm is building. The storm maximum is defined when R <0). The end of the storm samples is collected when R and O are more positive than the threshold voltage. After a pumping event based on transmission the internal computer recalculates the sampling schedule for the remaining filters. Up to six storms (high turbidity events) can be sampled with this programming sequence with 3 samples per storm.

Test Procedures

A series of laboratory tank tests and field calibration tests off a dock facility were designed to evaluate and calibrate the operation and sampling reproducibility of the AT-WTS. The choice of intake ports for each filter housing was a primary concern.

Laboratory Test

A rectangular stainless steel tank with a capacity of approximately 816 liters (215 gallons) was cleaned and filled with water filtered to two microns (um). An AT-WTS with the controller unit and pump assembly was placed on the bottom of the tank with a communication cable running to a personal computer to facilitate pre-programming and monitoring data flow as the test runs proceeded. Known concentrations of sediment from the New England Continental Shelf was introduced into the tank at concentration of about 3 and 3.3 mg/L. An electric outboard motor was used to maintain the sediments in suspension, but some settling of sediment was observed in the corners of the tank.

Nine ports on the AT-WTS pump head were fitted with filter holders containing pre-weighed 47mm diameter nucleopore membrane filters with 0.45um pore openings. The other nine parts on the pump head were closed off with blank fittings and were not involved during the test.

Two intake tips were evaluated during the laboratory tests (figure 3). One tip had a spring loaded check valve (CV) at the end which opened in response to pump flow. The second tip consisted of an open cylinder made of a porous resin material impregnated with tri-butyl tin to minimize biofouling (BT). An assessment of the different tips was carried out because the standard manufacturers spring activated check valve tip was thought to impede flow and movement of suspended matter onto the filters.

One series of three filter holders was fitted to the pump head with the standard check valve assemblies (CV) on the intake tip. Another series of three filter holders was fitted with the through hole tip (BT). A final set of three filter holders was used as procedural blank controls to correct for weight changes due to humidity and handling and were not involved in pumping events. Grab samples of the sediment suspension were also taken during each pump event. The sample was collected by immersing a graduated cylinder through the water column adjacent to the pump assembly as a sample was being pumped through the filter assembly. The grab sample was then filtered onto similar pre-weighed nucleopore filters.

During the tank tests pump speeds, flow rates, and total volume pumped were monitored and confirmed. At the end of the six pump events the filters were removed from their respective holders, rinsed with filter distilled water, and dried at room temperature under a laminar flow hood. The net sediment weights were determined and suspended matter concentration were calculated. The tank was flushed, cleaned, refilled with filtered water and a slightly higher concentration of sediment (3.3mg/L) was introduced and the entire procedure repeated.

Dock Test

Laboratory tests with shallow tank suggested that some cavitation was occurring as the gear pump motor pumped against a progressively clogged filter on the AT-WTS instrument resulting in electronic measurements of volume pumped that was erroneously low. To overcome this problem the quality control and calibration program moved to the Woods Hole Oceanographic Institution (WHOI) dock facility. Here, the pump and controller housing were mounted in the mooring frame and tested at a depth of approximately 15.5 meters. This subjects the unit to an additional 1.5 atmospheres of external pressure which minimizes any cavitation effects as the filters become clogged. A long communication cable allowed continuous monitoring of the unit during the test.

Because the laboratory tests (see results) indicated that the check valve pre-filtered the sample and biased the grain size distribution, the BT tip was used exclusively for all future tests and field deployments.

During each test at the dock, samples were collected with three filter holders fitted with the BT tips and the standard nucleopore filter membranes. Three filter holders deployed on the instrument but not pumped served as procedural controls. A standard oceanographic two liter niskin bottle was lowered to the same depth as the AT-WTS and a water sample was collected approximately half way through each pump event. The sample was transferred to a storage container for filtration and gravimetric analysis in the laboratory.

A collection bag (figure 2) was attached to the exit port of the gear pump assembly in order to collect the volume of water filtered. Upon completion of each pump event, the frame was raised and the water transferred from the collection bag into a graduated cylinder and the volume recorded. This volume was compared to the volume calculated by the AT-WTS software.

After the final sample was collected, the filter holders and controls were removed and taken to the laboratory for analysis. The filters were rinsed four times with filtered distilled water, air dried under a laminar flow hood, and weighed on a micro balance. Samples from the niskin bottle were filtered using similar pre-weighed filter membranes and processed and weighed in a similar manner.

Results and Discussion

A comparison of results using the CV and BT tips are shown in figure 4 and table 1.

Results for the two experiments with slightly different total suspended matter concentrations (TSM) indicate that the filter holders with the BT tips collected 96 + 8.76% and 94 + 5.82% of the TSM. In contrast, the filter holders with the CV tips collected only 79 + 5.66% and 36 + 23.52%. The measured concentration from the grab samples was used to determine the percent recovery (table 1).

In order to assess the quality as well as the quantity of suspended matter, samples collected using both tips were examined by optical and scanning election microscopy (SEM). The inorganic particles were counted and sized and the results are displayed in table 2. The range of particles sized was from >100-10um (very fine sand-medium silt). No analyses of the >10um was performed. Results indicate up to 18 percent more material in the coarser size range of 100-50um (sand size) was collected on filters sampled with the BT than those of the CV tips. Alternatively, 23 percent less suspended matter in the size range of 50-10um (silt size) was collected on filters fitted with the BT assembly than those filter holders fitted with the CV. The grain size distribution of samples collected from the grab samples are similar to that of the filters sampled by the CV.

The lower sand fraction (100um-50um) from the grab sample compared with that of the BT samples may be a result of a non-uniform distribution of suspended matter in the tank maintained with the electrical outboard motor. The AT-WTS typically sampled over an eight to twelve minute duration whereas the grab sample was taken in less than thirty seconds. Coarser particles may also have been retained at the bottom or sides of the graduated cylinder during transfer operations to the filtration apparatus. The modal pattern is the same for the three sample sets (50-10um), however the filters with the BT tips collected a coarser distribution. The CV tip is suspected to have biased the distribution of particles toward the fines. We found sand size particles trapped within the inner mechanism of the CV indicating that prefiltering of the coarse particles was occurring. Since the sand-sized fraction is important to evaluate during storms, the CV assembly was abandoned from further use and testing.

Results of calibration tests at the dock for suspended matter weights collected by the AT-WTS unit BOB fitted with the blank tip (BT) compared with those of the niskin bottle samples are shown by a linear regression plot in figure 5. A fair correlation exists between the weights of sediment collected between these two sampling techniques (r =.540). However, statistical analysis at the 90% to 99% confidence levels showed no linear dependency between the two variables. A dashed line showing a perfect correlation (1:1) additionally demonstrates the comparison between the plotted regression line and the scatter of data points about it. An average maximum weight of 4.28mg/L was collected by the niskin bottle during January, 1992 (table 3), whereas the WTS unit BOB recovered an average weight during the same time period of 3.01mg/L. A comparison of the range of average weights determined from sample variability (standard deviation) overlaps in 75 percent of the results.

A linear regression plot of total suspended matter recovered from the AT-WTS unit TED compared with that of the niskin bottle reveals an excellent correlation (r^2 =.943) between the sample weights collected by these two devices (figure 6). A maximum average weight of 6.60mg/L was collected by the niskin bottle during February, 1994 (table 3). A corresponding maximum weight of 6.20 mg/L was also collected by the WTS unit during this period. There appears to be somewhat less sample variability about the mean than with samples collected by WTS unit "BOB" as shown from table 3. Statistical tests reveal that the two variables are linearly related at the 98 per-cent confidence interval.

The suspended matter weights collected by WTS "BOB" display more scatter. This probably reflects the fact that sampling took place during periods of significantly higher tidal flow. Maximum tidal currents in the dock area typically range from 180-231 cm/sec (3.5-4.5 knots) and can reach a spring tide maximum of about 360 cm/sec (7 knots). Analysis of tidal data reveals that approximately twenty five percent of the samples were taken during a period of mean peak tidal current velocity. In the case of the dock tests, the AT-WTS samples are integrated over a period of approximately eight to twelve minutes, whereas the niskin bottle is taken in less than a few seconds and represents more of a "snapshot" of the water column. Thus these two sampling devices are very likely collecting somewhat different water samples especially during these turbulent flow conditions. Optical microscopy and SEM examination of selected filter sets from the niskin bottle and both the AT-WTS units reveals a similar composition and size of suspended material. The material consisted of plant fragments, detrital particles, amorphous organic masses, biogenic material and rock fragments.

The AT-WTS unit "TED" was generally sampled during slack or near slack tidal flow. The less turbulent current flow may account for the more uniform concentrations of suspended matter between unit TED and niskin bottles with samples than obtained with unit "BOB" and the Niskin bottle samples.

The pump volume calibration for the two AT-WTS systems is displayed in figures 7 and 8. For the range of volumes measured (400-1300mls) the average difference between volume collected and volume estimated electronically by the AT-WTS unit "BOB" was 41.99 + 23.68 milliliters. This is about a 5.79% difference between the calculated volume and the collected volume. An excellent relationship between the two measured volumes was determined by linear regression analysis with a correlation coefficient of 0.977. Statistical tests of significance and confidence limits (Z-transformation) for the correlation coefficient at the ninety five percent level shows that the two variables (AT-WTS volume and the collected volume) show a strong linear dependency and there is no statistical difference between the data and the 1:1 regression line. This relationship is only valid for the range of volumes analyzed.

Figure 8 shows an even better linear agreement for the AT-WTS unit "TED" with a correlation coefficient of .990. Similar statistical tests applied to this data at the ninety five percent confidence interval reveals that a strong linear relationship exists between the two variables and there is no statistical difference between the calculated and ideal (1:1) linear regression line.

The difference between the volume of water collected and that determined by the program software over the testing period at the dock was 28.5 + 18.36 milliliters. This results in about an average difference of about three percent between the volume calculated by the computer algorithm and the volume was actually collected in the sample bag.

Conclusions

We have described the operation of the McLane AT-WTS Mark 5-18 in-situ suspended sediment instrument and the results of laboratory and field tests.

Results from the laboratory flow tank and SEM analysis of particle distribution indicate that the standard manufacturers spring loaded check valve intake tips appear to pre-filter coarser (sand size) particles from the sample and that the percent recovery (on a weight basis) is 15-20% less than the through-hole tips (BT). The BT tips are now used for all deployments in field programs.

A calibration test program has been designed and implemented prior to each deployment to insure quality control and functional reproducability of the AT-WTS units. The total suspended matter (TSM) concentration determined with the AT-WTS system recovered on filters at a depth of 15.5 meters in seawater is compared with TSM values collected by using a niskin bottle at the same depth, time and location. Statistical tests and results of linear regression analysis indicates that a better correlation exists between the TSM values of TED and the niskin bottle (r^2 = .943) than that of BOB and the niskin bottle (r^2 = .540). This appears to be a result of higher current flow and more heterogeneous suspended matter concentrations at the dock facility during intervals sampled by the AT-WTS unit BOB. Over twenty five percent of the samples taken were during a period of peak tidal flow. These turbulent flow conditions as well as the nature of the AT-WTS unit integrating the sample collection over a much longer period of time than the "snapshots" sample collected by the niskin bottle may account for this difference. All calibration tests are now done at slack tide. Tests to determine the accuracy of both AT-WTS units to electronically determine the volume of seawater filtered was in excellent agreement (less than six percent difference) with the volumes actually collected and measured. There was no statistical difference determined at the 95 percent confidence interval between the volumes collected and volumes determined by the software. This relation is such that one variable can be used effectively to predict the other. Thus there is no justification for applying a systematic correction to the range of volumes analyzed and collected by the AT-WTS units.

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LIST OF FIGURES

line = linear regression for data points; dashed line = a 1:1 relationship.

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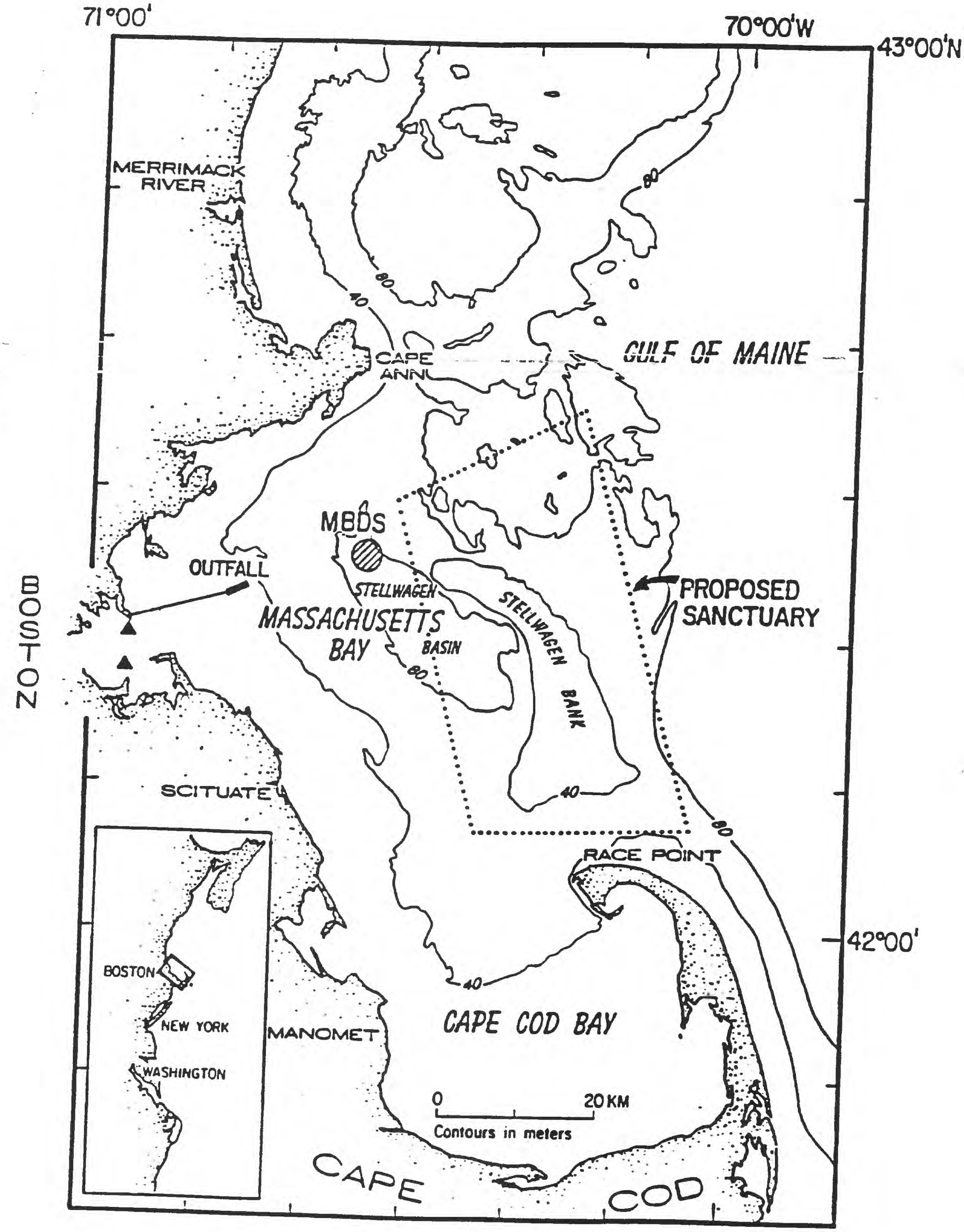

71°00'
70°00'W
43°00'N
MERRIMACK
RIVER
80
40
80
CAPE
ANN
GULF OF MAINE
MBDS
OUTFALL
BOSTON
STELLWAGEN
MASSACHUSETTS
BAY
BASIN
80
STELLWAGEN
BANK
PROPOSED
SANCTUARY
SCITUATE
40
80
RACE POINT
42°00'
BOSTON
NEW YORK
WASHINGTON
40
MANOMET
CAPE COD BAY
0
20 KM
Contours in meters
CAPE
COD

Figure 1

1. Controller Housing

Pump Assembly:

2. Stepper Motor
3. Manifold
4. Tubing
5. Gear Pump
6. Filter Holders

7. Volume Collection Bag
8. Frame
9. Laptop Computer

a. Communication cable
b. Stepper motor cable
c. Gear pump cable
d. Optical sensor connector

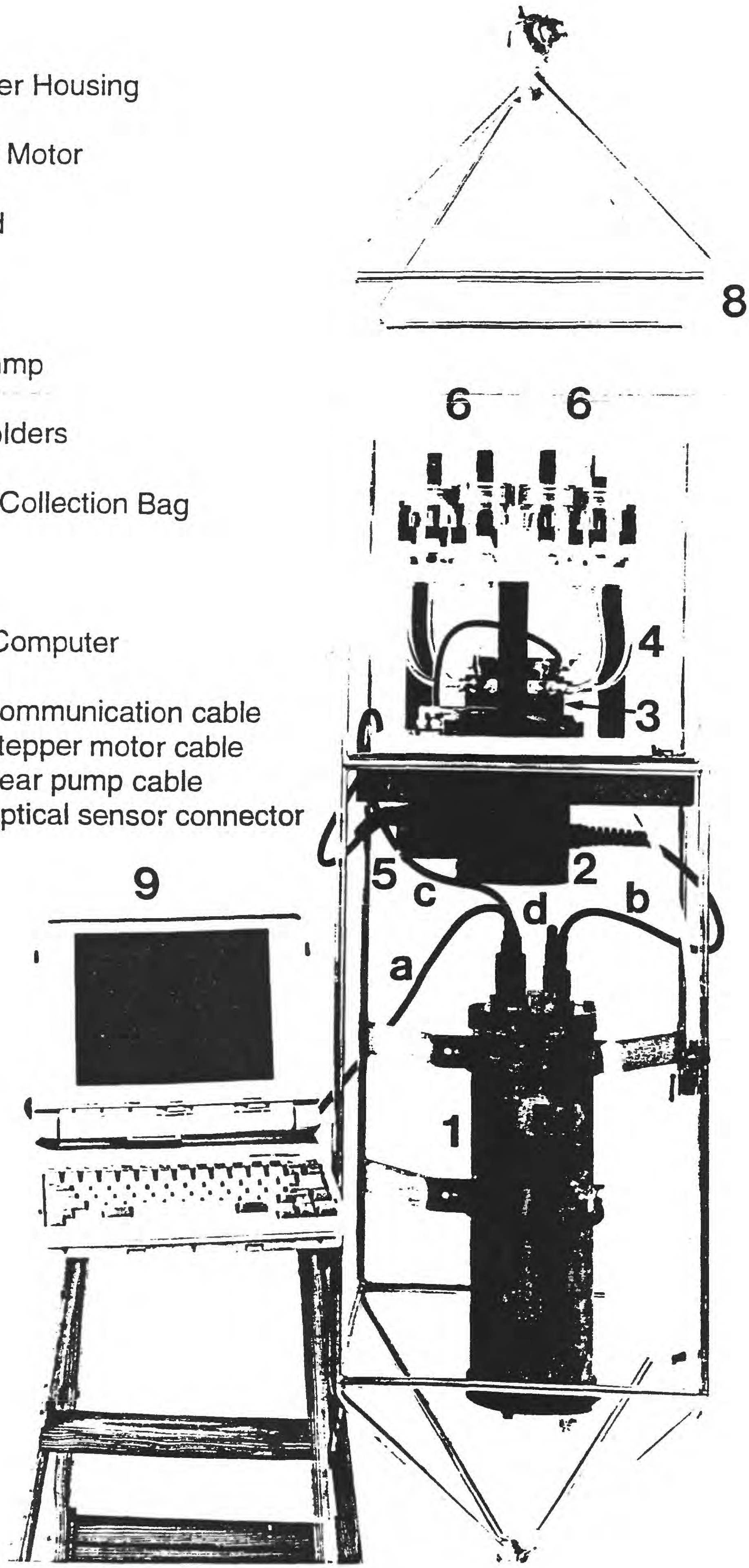


Figure 2

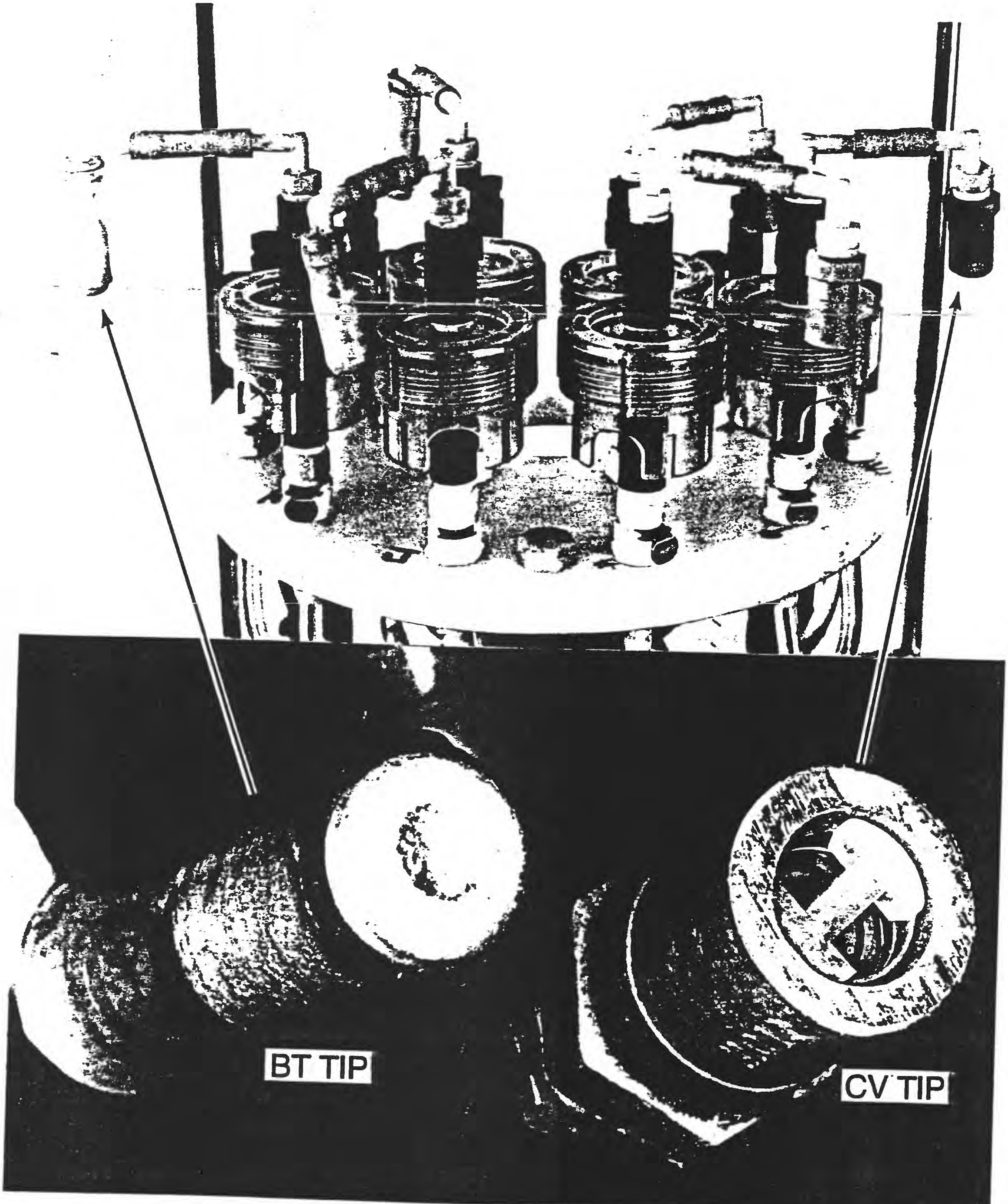
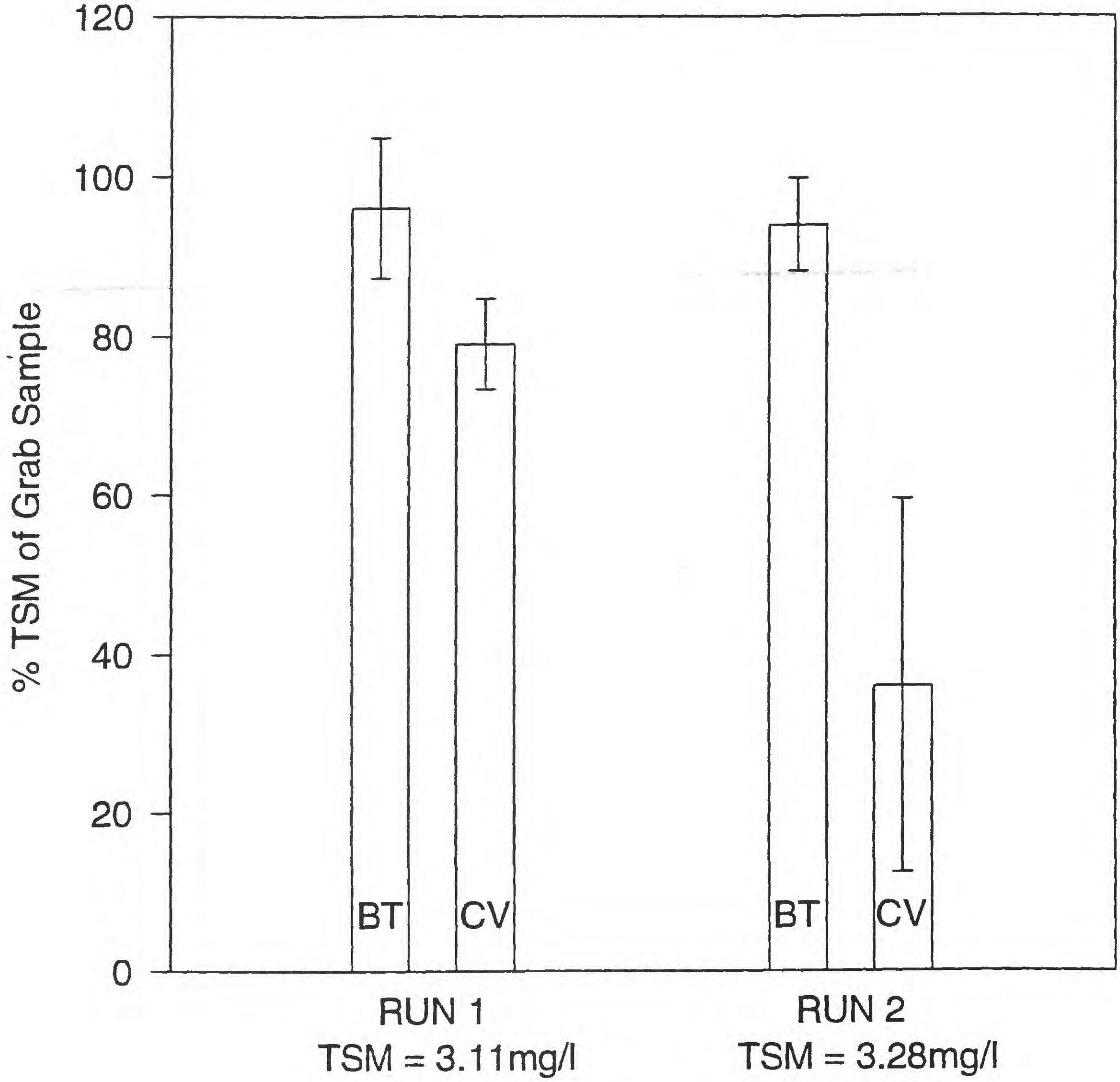


Figure 3

Figure 4



120
100
80
60
40
20
0
% TSM of Grab Sample
BT
CV
BT
CV
RUN 1
TSM = 3.11mg/l
RUN 2
TSM = 3.28mg/l

FIGURE 5

WHOI-DOCK CALIBRATION TEST(WTS-BOB)
$Y=.54x+1.69$ $r^2=.54$
dashed line = 1:1 relationship

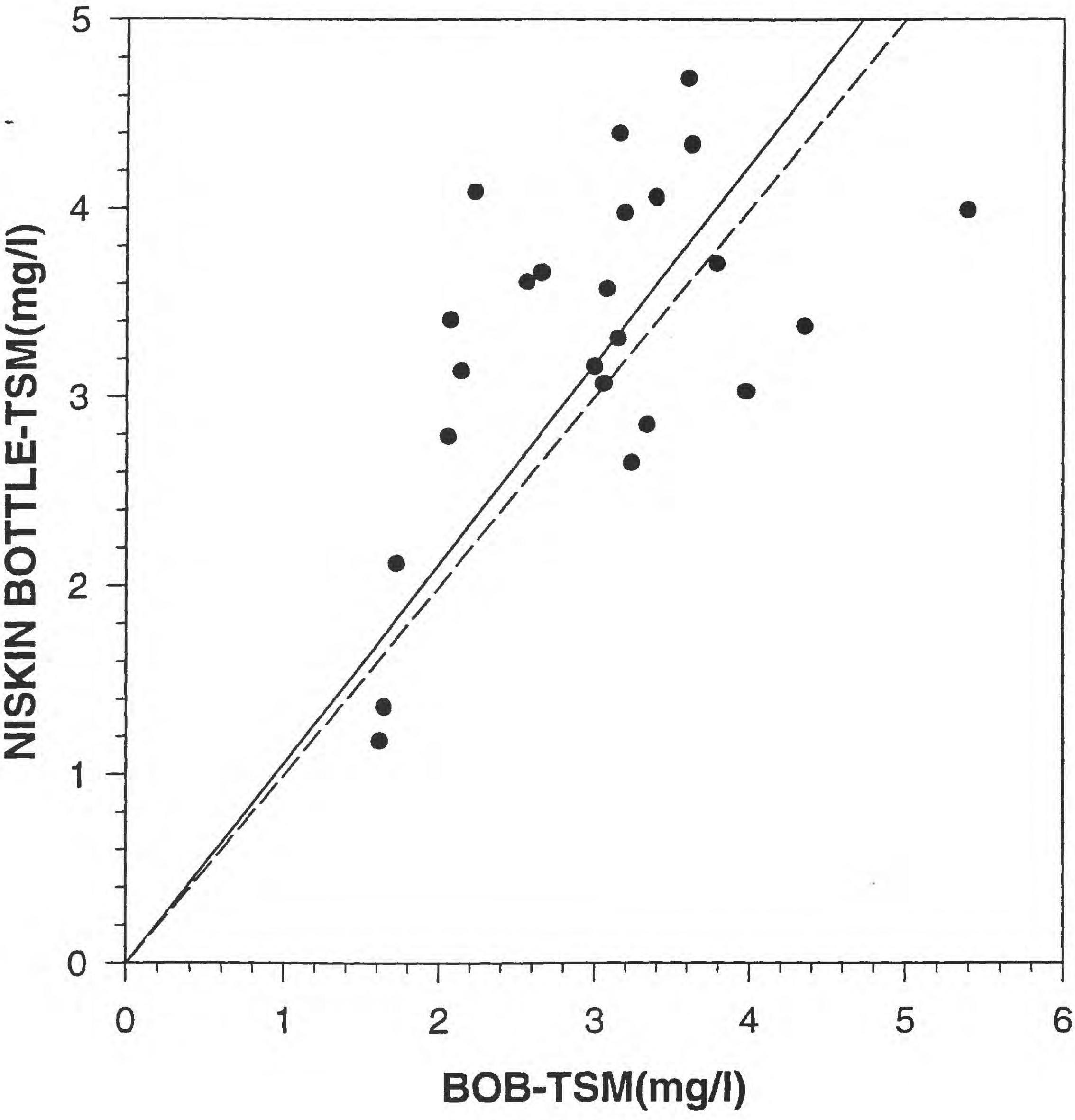


FIGURE 6

WHOI-DOCK CALIBRATION TEST(WTS-TED)

$y=.89x+1.05 \quad r^2=.943$

dashed line = 1:1 relationship

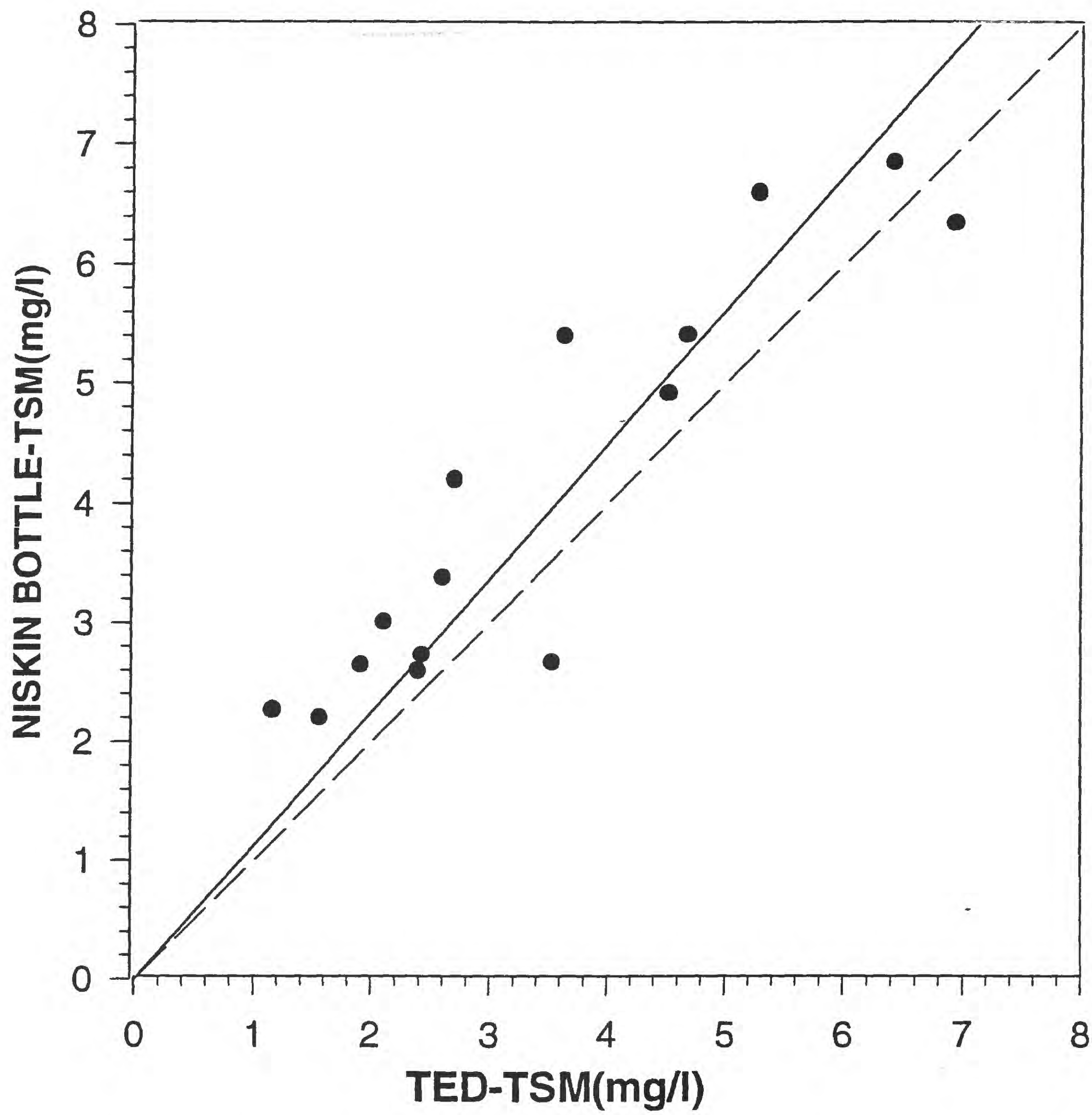


FIGURE 7

VOLUME RELATION FOR AT-WTS(BOB)
$y=.925x+29.15$ $r^2=.977$
dashed line = 1:1 relationship

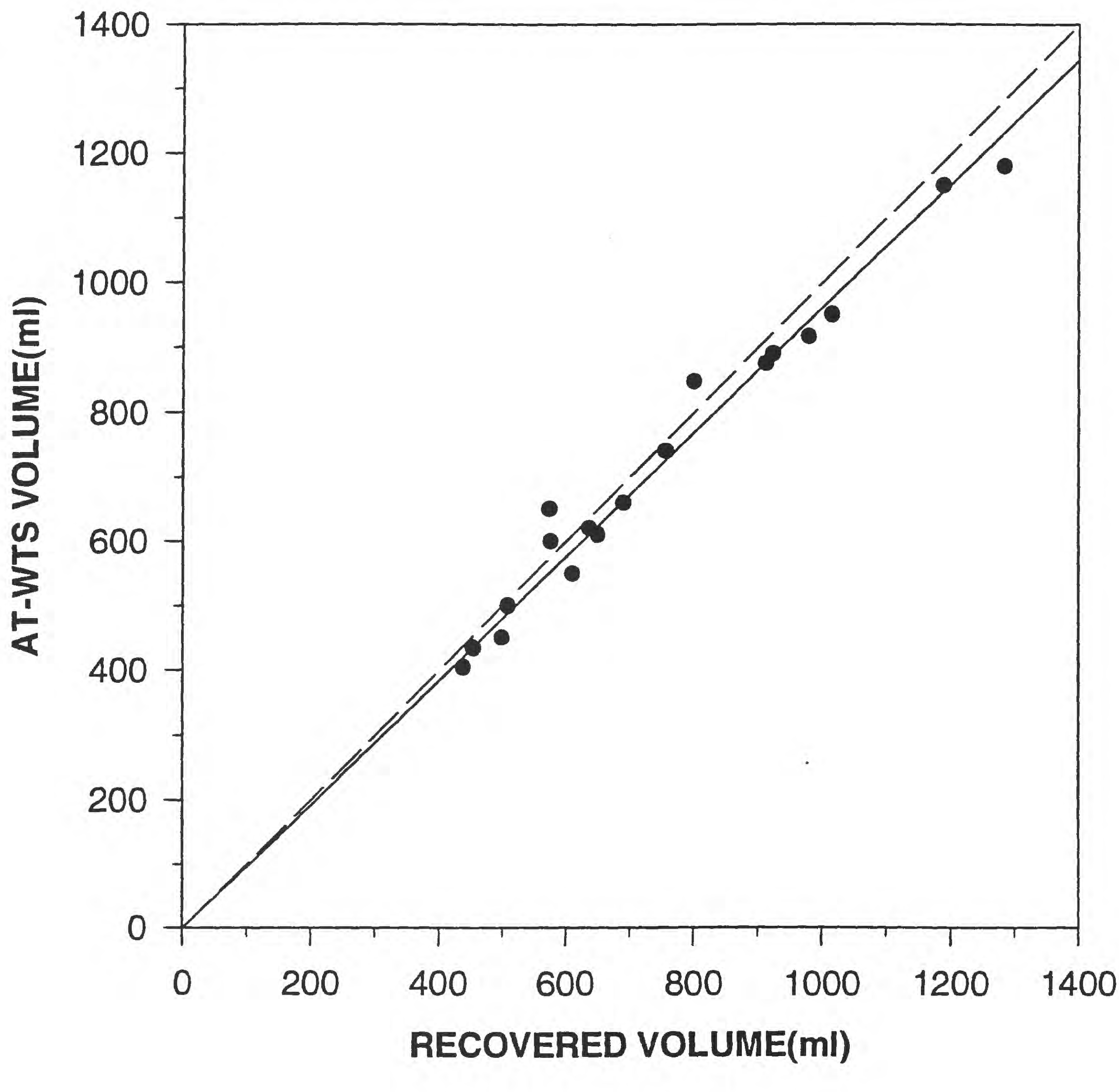


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FIGURE 8

VOLUME RELATION FOR AT-WTS(TED)
$Y=.937x+29.18 \quad r^2=.990$
dashed line = 1:1 relationship

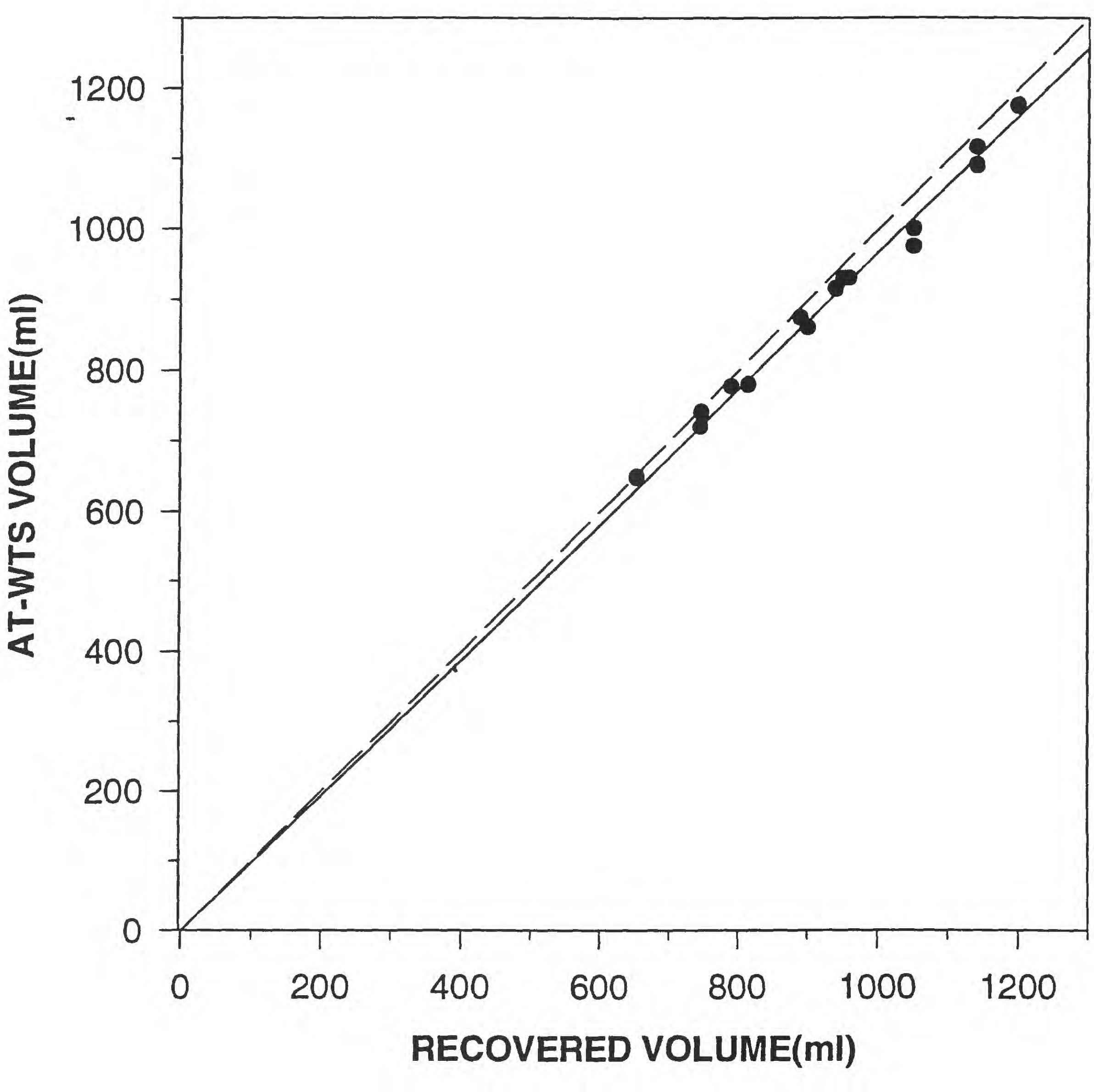

TABLE 1

DEVICE(TIP)	WEIGHT (mg/l)	MEAN (sd)	GRAB CONCENTRATION(mg/l)	% RECOVERY
AT-WTS(CV)	2.72 2.46 2.25	2.47(.14)	3.11	79
AT-WTS(BT)	3.49 2.63 2.80	2.97(.26)	3.11	96
GRAB	3.17 3.15 3.01	3.11(.09)	3.11	100
AT-WTS(CV)	2.17 1.66 2.10	1.19(.28)	3.28	36
AT-WTS(BT)	3.28 3.07 2.93	3.09(.18)	3.28	94
GRAB	3.58 3.46 2.80	3.28(.42)	3.28	100

TABLE 2

DEVICE(TIP)	>100um.(%)	100-50 um.(%)	50-10 um.(%)
AT-WTS(bt)	6	26	68
AT-WTS(cv)	1	8	91
GRAB	1	9	90
MARINE SEDIMENT	0	7	67

TABLE 3

DATE	BOB-MEAN TSM (mg/l)	NISKIN MEAN TSM(mg/l)
3/91	3.13(.46)	3.10(.46)
5/91	2.99(1.20)	3.26(.42)
1/92	3.01(.71)	4.28(.16)
8/92	4.24(1.04)	3.29(.61)
9/93	2.74(.59)	3.29(.13)
3/94	1.62(.23)	2.49(.88)
5/94	3.60(.20)	4.15(.50)
2/95	2.66(.53)	3.59(.42)
	TED- MEAN TSM (mg/l)	
2/91	2.45(.07)	2.67(.07)
10/91	4.27(.56)	5.24(.28)
3/92	1.69(.19)	2.37(.24)
2/94	6.20(.84)	6.60(.30)
9/94	2.47(.32)	3.53(.61)

( )= standard deviation