2. Methods

The following subsections briefly summarize the methods used during this survey. The combined work/quality assurance project plan (W/QAPP) for *Cruise Ship Sampling* (Battelle 2001)[1] contains additional details on survey sampling methods.

2.1. Vessel Specifications and Test Conditions for Cruise Ships

The vessels provided a range of study platforms in terms of vessel sizes, types, and rates of discharge studied. Table 2 lists each vessel's specifications as they pertain to the study.

2.2. Method Descriptions:

Navigation. Vessel positioning during sampling operations was accomplished using the OSV *Anderson* Differential Global Positioning System (DGPS) interfaced to Battelle's NavSam© navigation system. The DGPS receiver has six dedicated channels and is capable of locking onto six different satellites at one time. To correct the Global Positioning System (GPS) calculations, the DGPS receives correction data from one of the United States Coast Guard DGPS broadcast sites in Florida: Key West, Virginia Key, Cape Canaveral, Macdill AFB, and Egmont Key. This capability ensured strong signal reception, and accurate and reliable positioning with 2-second updates. The DGPS was operated and maintained according to the operator's manual.

A calibration check of the navigation system vs. known benchmarks was conducted twice daily to verify that the system was working properly. The checks were conducted prior to departing the dock and following arrival at the dock during daily operations.

Plume Tracking Using the Battelle Ocean Sampling System. Plume tracking was conducted using the Battelle Ocean Sampling System (BOSS) deployed from the OSV *Anderson*. Three types of plume tracking activities were conducted during the survey: a shakedown survey, four background surveys conducted on each survey day for each of the four ships, and the four plume tracking surveys. Each type of survey is briefly discussed below.

The towfish with *in situ* sensor package (BOSS) was used to conduct all of the plume tracking activities. The sensor package included a conductivity, temperature, depth (CTD) sensor, and a fluorescence sensor (set at 0-5µg/L – referred to as Dye 1). A second fluorescence sensor (set at 0-50µg - referred to as Dye 2), was used in case concentrations exceeded the range of the first sensor. Table 3 lists the field measurements acquired from the BOSS during each monitoring event.

[1] Battelle. 2001. Work/Quality Assurance Project Plan for Cruise Ship Sampling. Prepared for U.S. Environmental Protection Agency Oceans and Coastal Protection Division, Washington, DC. Contract No. 68-C-00-121, Work Assignment 1-23. 33pp+apps.

Table 2. Vessel Specifications and Test Conditions for Cruise Ships.

Most of the data were provided by the cruise lines.

Specification or Test Condition	**Cruise Ship**			
	Majesty	***Explorer***	***Paradise***	***Fascination***
Vessel Specifications				
Length/Beam	268.3m/32.6m	311.13m/38.6m	260.6/31.4	260.6/31.4
Draft to lowest tip of screws	7.50 m	8.80 m	7.75 m	1.5 m
Draft to bottom of ship	7.70 m	8.80 m	7.75 m	7.75 m
Size of tank in study	220 m^3	25.9 m^3	175 m^3	30 m^3
Type of tank	Gray water	Black water	Gray water	Gray water/ laundry
Location of discharge port	N/A	DN 150 FRAME 75-76	Starboard, frame 136	Port side, frame 32
Vertical depth	5.6 m	6.4	6 m	6.35 m
Distance from bow	~172.36 m from forward PP	225 m	146 m at waterline	200.8 m at waterline
Distance from stern	~65.64 m from aft PP	66.6 m	114.6 m at waterline	59.8 m at waterline
Distance from screws	54.25 m	57.6 m	99.8 m	~15.2+m
Distance from keel	1.9 m	2.4 m	55.16 m	28.81 m
Distance from water line	5.6 m	6.4 m	6 m	1.25 m
Size of discharge pipe and through-hull fitting	203 mm	203 mm	200 mm	88.9 mm
Discharge pump rate (rated)	220 m^3/hr	50 m^3/h	50 m^3/hr	50 m^3/hr
Number of propellers	2	3	2	2
Diameter of propellers	4.9 m (4 blades)	5.4 m fixipod 5.6 m azipods	5.2 m Azipods	5.2 m
Direction of propeller rotation (aft view)	CW (port) CC (starboard)	CC (starboard) CW (port) CW (fixipod)	CC (port) CW (starboard)	CC (port) CW (starboard)
Test Conditions				
Vessel speed during test: Speed Over Water (SOW)	17.4 knots	19 knots	15.0 knots (see Survey Chronology)	9.1 knots (see Survey Chronology)
Volume of seawater added to tank	113 m^3 gray water only	16.6 m^3	108 m^3 gray water only	27 m^3 gray/ fresh water
Volume of test solution at discharge Time Zero (T_0)	113 m^3 + 114 L dye (~0.1m^3 dye)	18 m^3 (includes 133 L dye - ~0.1m^3 dye)	108 m^3 + 133L dye (~0.1m^3 dye)	27 m^3 + 137L dye (~0.1m^3 dye)
Date - Time discharge began (T_0)	8/10/01 - 18:44	8/11/01 - 19:43	8/12/01 - 19:00	8/13/01 - 19:15
Time discharge completed (T_{end})	19:41	20:01	19:30	19:35
Volume in tank when discharge completed (T_{end})	7 m^3	1.2 m^3	40 m^3	3 m^3
Volume in tank after 20 min (calculated)	78 m^3	~1.2 m^3	62.6 m^3 **	3 m^3 ***
Number of pumps used to discharge water/dye solution for 20 min.	1 0-20 min 2 20+ min	1	2	1
Discharge rate of pump(s) (rated/actual)	220/112 m^3/hr	50/56 m^3/hr	50/68.0 m^3/hr	50/72 m^3/hr
Amount of dye in tank at T_0	30 gal.	35 gal.	35 gal.	36 gal.

** Calculation: 108 m^3 - 40 m^3 = 68 m^3 , and 68 m^3 in 30 min pumping = 2.27 m^3/min, then 2.27 m^3/min * 20 min = 45.4 m^3, and 108 m^3 – 45.4 m^3 = 62.6 m^3.
***Calculation: 27 m^3 - 3 m^3 = 24 m^3 , and 24 m^3 in 20 min pumping = 1.2 m^3/min, then 1.2 m^3/min * 20 min = 24 m^3, and 27 m^3 – 24 m^3 = 3 m^3.

Table 3. Summary of Field Instruments Measurements

Parameter	Lab	Units	Instrument
Conductivity	Battelle	Mmhos/cm	OS200 CTD
Temperature	Battelle	°C	OS200 CTD
Pressure	Battelle	M	OS200 CTD
Transmissometry/turbidity	Battelle	m-1	Seatech 20-cm (660nm) (2)/Seapoint RWT Sensor
Bottom depths	*Anderson*	M	Furuno FCV-52
Navigational position	*Anderson*	Degrees	Northstar 942X
Ocean current velocity	Battelle	Cm/sec	RD Instruments ADCP WHM600-I-UG6
Sigma-t	Battelle	no units	OS200 CTD (calculated)
Salinity	Battelle	PSU	OS200 CTD (calculated)
Rhodamine fluorescence	Battelle	µg/L	Seapoint RWT fluorometer

The rhodamine fluorometer measures dye concentrations (ppb) directly. All dye data reported in this document were collected from the Dye 2 sensor (set to measure dye concentrations ranging from 0-50 µg/L). These *in-situ* fluorescence measurements were electronically recorded continuously throughout multiple passes for each plume monitored. All rhodamine dye fluorescence data presented in this report are corrected for temperature.

The station/sample location number, GPS coordinates, date and time, depth of the water column, and any observations associated with the sampling at each sampling location were made in the field survey logbook. Each sample was assigned a unique ID and label by NavSam©, which also electronically stored the field and sensor data. Exceptions are noted in Section 5.

BOSS sensor data were collected continuously during plume tracking activities. The BOSS was deployed approximately 10 ft. off of the port side of the *Anderson* using the boom crane to minimize the impact of the *Anderson's* wake and propellers on the monitoring activities.

Shakedown Survey. A shakedown survey was conducted to determine whether the *in-situ* fluorescence sensors were able to detect dye concentrations of <10µg/L. The *Anderson* transited to a location in the ocean in the vicinity of the study area. Dye was carefully added directly into the ocean (less than 0.5 gal.) via a funnel and a long Tygon tube as the *Anderson* transited at a speed of approximately 5 kts. After the dye addition, the *Anderson* was maneuvered to run a transect through the dye. When the *in-situ* dye fluorescence instruments registered faint spikes indicating that dye was detected by both sensors, the *Anderson* headed back to Miami to make preparations for tracking the *Majesty* plume on the following day.

Background Transect Monitoring and Sampling. A single background transect was conducted on each survey day in the vicinity of the rendezvous point before the respective cruise ship arrived on station (Figures 2-5). BOSS sensor data was collected continuously along transects while on station waiting for the cruise ship. Samples for dye sensor calibration were collected at various depths ranging from 2 to 12 m at locations along the length of the transect.

Plume Transect Monitoring and Sampling. The transect configuration and the sampling locations along each plume transect were different for each cruise ship. Each configuration varied based on how the dye plume behaved in the existing currents after the dye was released. During the release of the dye from each cruise ship, drogued buoys equipped with lights and radar reflectors were released at approximately two-minute intervals (beginning when dye release was initiated) to permit easier tracking of the sub-surface plume. The drogues for each buoy were tethered ~2 m below the bottom of its associated buoy so that any existing surface currents would carry the drogues along with the targeted plume. Buoys were used to aid in tracking the plume. The deployment and retrieval locations were recorded by hand for all vessels except the *Majesty*.

After the cruise ship deployed the first buoy prior to passing the *Anderson* indicating the beginning of dye release, the *Anderson* began maneuvering to enter the plume on a track nearly perpendicular to the cruise ship's heading. The first transect (considered to be the initial dilution) was conducted at the surface (approximately 2 m deep). Samples for dye were collected on this first transect at the surface for every ship. The second, third, and fourth transects were with few exceptions taken at 5m, 8m, and 12m, respectively. In general, the dye samples were taken along these transects as well. As time progressed, transect depths and sampling locations were determined at the discretion of the EPA Chief Scientist (see Sampling Log Data in Appendix B). Table 4 shows the number of background and in-plume transects conducted for each cruise ship and the number of dye samples collected from locations along the selected transects. Additionally, the holding tanks (spiked with the Rhodamine dye) of each monitored cruise ship were sampled to determine actual dye concentration in the tanks prior to discharge. The numbers of samples collected from these tanks are also shown in Table 4.

Table 4. Numbers of Samples Collected and Plume Tracking Transects Completed.

Cruise Ship	Number of Plume Transects	Numbers of Discrete Samples		
		Cruise Ship Samples	Background Discrete Samples	Plume Discrete Samples
		Rhodamine Dye	Rhodamine Dye	Rhodamine Dye
Majesty	23	4*	5	2
Explorer	19	5	5	5
Paradise	17	5	5	8**
Fascination	7	5	5	9**
Survey Total	66	19	20	24

*First sample collected before T=0. Not included in calculations.
**Additional samples were collected (only five samples were planned for each transect).

Average values of depth and dye concentration were taken along each transect for each cruise ship from the point where dye values exceeded background levels until they returned to background levels. Plume width measurements were also made using the same points for obtaining average depth and dye concentrations.

Additional samples, above the five planned dye samples, were taken during monitoring operations for the *Paradise* and *Fascination*.

Upon survey completion, the samples were shipped in coolers containing ice to Battelle for final analysis. Before shipping, the sample custody forms were completed and placed in a sealed Ziploc bag that was taped to the inside of the cooler lid. The Battelle Field Custodian, Mr. Tim Kaufman, shipped *in-situ* plume dye samples from Miami and received them at Battelle. He also received sample shipments from the cruise lines for samples collected aboard the cruise ships.

Sample Storage Conditions. Discrete rhodamine dye samples collected aboard the cruise ships were stored chilled at ~ 4ºC. Each cruise ship was provided a shipping cooler and given instructions to store and ship samples on ice. Additional sample storage conditions are presented in Table 5.

Table 5. Analyte, Sampling Method, Volume, Preservation, and Holding Times.

Analyte (Analytical Laboratory)[(a)]	Matrix	Method	Sample Volume	Container Type	Preservation	Holding Time
Laboratory Analyses						
Rhodamine dye (Battelle)	Water	Seapoint RWT Sensor	500 mL	Polyethylene plastic	Cool, ~ 4°C	undetermined
Field Analyses						
Temperature (BDO)	Water	OS200 CTD	NA	NA	NA	*In situ*
Depth (BDO)	Water	OS200 CTD	NA	NA	NA	*In situ*
Transmissometry/ Turbidity (BDO)	Water	Seatech 20-cm (660nm)	NA	NA	NA	*In situ*
Conductivity (BDO)	Water	OS200 CTD	NA	NA	NA	*In situ*

(a) BDO: Battelle Duxbury Operations
NA = Not applicable.

Acoustic Doppler Profiles. Current data from an acoustic Doppler current profiler (ADCP) on board Royal Caribbean Cruise Line's *Explorer* was obtained from NOAA. This data was collected during transit through the site during the plume tracking survey on August 11.

3. Survey Results and Discussion

All plume tracking and sampling operations were successfully completed over the targeted 4-day period (spanning August 10-14) during which four separate cruise ship discharge plumes were continuously monitored and sampled. Numbers of transects conducted and samples collected are presented in Table 4.