This document contains the report on characterization of nitrogen compounds for four cruise ships operating in Alaska. The whole report, including the appendices, can be downloaded from:
http://www.epa.gov/owow/oceans/cruise_ships/nitrogen.html

Sampling Episode Report
Nitrogen Compounds Characterization
Sampling Episodes 6517 Through 6520

November 2006

United States Environmental Protection Agency

Sampling Episode Report
Nitrogen Compounds Characterization
Sampling Episodes 6517 Through 6520

U.S. Environmental Protection Agency

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Office of Wetlands, Oceans, and Watersheds

Engineering and Analysis Division
Office of Science and Technology

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ACKNOWLEDGMENT AND DISCLAIMER

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Sampling Episode Report for Nitrogen Compounds Characterization during 2005 Alaska Cruise Season

This Sampling Episode Report (SER) describes the sampling and analysis activities to characterize the nitrogen compounds in wastewater (graywater and sewage) generated and discharged by the cruise vessels Holland America Veendam (Veendam), Norwegian Star (Star), Island Princess (Island), and Holland America Oosterdam (Oosterdam) while in Alaska waters. This sampling took place from August 1 through August 31, 2005, under the direction of the U.S. Environmental Protection Agency (EPA). The sampling program is part of EPA's data collection effort to evaluate whether to develop wastewater discharge standards for cruise vessels, under 33 USC 1901 Note, authorized to carry 500 or more passengers for hire when operating in the waters of the Alexander Archipelago or the navigable waters of the United States within the State of Alaska or within the Kachemak Bay National Estuarine Research Reserve.

This sampling addressed only nitrogen compounds (ammonia, total Kjeldahl nitrogen, and nitrate/nitrite) and certain benchmark analytes (chemical oxygen demand and total suspended solids). This sampling was performed to supplement more extensive sampling episodes conducted during the 2004 Alaska cruise season onboard these same four cruise vessels because some of the 2004 results for nitrogen compounds were anomalous. EPA will use information from the 2004 and 2005 sampling programs to characterize wastewater generated and discharged by large cruise vessels with advanced wastewater treatment systems.

Grab composite samples were collected of the influents to and effluents from the advanced wastewater treatment systems (combined graywater and sewage) onboard the four sampled vessels. The Veendam, Star, and Island each operate one treatment system for treatment of combined sewage and graywater. The Oosterdam operates two treatment systems: one to treat sewage and galley wastewater and one to treat other graywater sources. For each ship, wastewater samples were collected for five 7-hour sampling periods—one sampling period each week for five consecutive weeks.

Ammonia, total Kjeldahl nitrogen (TKN), chemical oxygen demand (COD), and total suspended solids (TSS) were detected in all influent to treatment samples. Nitrate/nitrite was not detected in any influent to treatment samples for the Star or Island treatment systems, or for the Oosterdam graywater treatment system. Nitrate/nitrite was detected in most influent to treatment samples for the Veendam treatment system and the Oosterdam sewage/graywater treatment systems.

All five wastewater treatment systems successfully removed most COD (>82%) and TSS (>89%). They also removed some ammonia (ranging from 30 to 86%) and TKN (ranging from 49 to 89%). Nitrate/nitrite levels remained relatively unchanged. Nitrogen removed by the treatment systems is likely taken up by the microorganisms in the bioreactors and removed from the systems in the waste biosludge.

1.0 INTRODUCTION

This Sampling Episode Report describes the Environmental Protection Agency's sampling and analysis activities to characterize the concentrations of nitrogen compounds (ammonia, total Kjeldahl nitrogen (TKN), and nitrate/nitrate) in graywater and sewage generated on and treated by four cruise vessels (Holland America Veendam, Norwegian Star, Island Princess, and Holland America Oosterdam) while in Alaska waters. This sampling episode took place from August 1 through August 31, 2005, under the direction of the Engineering and Analysis Division of the Office of Science and Technology and the Oceans and Coastal Protection Division of the Office of Wetlands, Oceans, and Watersheds of the U.S. Environmental Protection Agency (EPA).

This sampling program is part of EPA's data collection efforts to evaluate whether to develop wastewater discharge standards for cruise vessels authorized to carry 500 or more passengers for hire when operating in the waters of the Alexander Archipelago or the navigable waters of the United States within the State of Alaska or within the Kachemak Bay National Estuarine Research Reserve (hereafter referred to as Alaska waters). Such regulations are authorized by "Title XIV - Certain Alaskan Cruise Ship Operations" of the Miscellaneous Appropriations Bill (H.R. 5666) passed by Congress on December 21, 2000 in the Consolidated Appropriations Act of 2001 (Pub L. 106-554, Sections 1401-1414, 33 USC 1901 Note). The data and information gathered through this sampling episode were collected using EPA's authority under Section 308 of the Clean Water Act, as also provided by Title XIV. The cruise lines voluntarily provided information and data gathered for and represented in this report, notwithstanding the above authority, in the interest of research for the improvement of wastewater treatment standards.

During the 2004 Alaska cruise season, EPA conducted a large onboard sampling program consisting of sampling episodes onboard these same four cruise vessels. Each vessel has a different advanced wastewater treatment system; each sampling episode consisted of five consecutive 24-hour sampling periods. The 2004 sampling program focused on characterizing the wastewater (graywater and sewage) onboard cruise vessels and evaluating the performance of

the advanced wastewater treatment systems. The results of these 2004 sampling episodes can be found on EPA's website at www.epa.gov/owow/oceans/cruise_ships/results.html.

The following table provides general information for the four cruise vessels sampled in 2004 and 2005:

Ship	Launched	Gross Tons	Number of Passengers (a)	Number of Crew	Length (feet)	Beam (feet)	Number of Decks
Veendam	1996	55,451	1,266	588	720	101	10
Star	2001	91,740	2240	1,000	965	105	15
Island	2003	88,000	1,950	850	964	106	16
Oosterdam	2003	85,000	1,824	800	951	105.8	11

(a) Based on 2 per stateroom.

All four ships follow 7-day cruise itineraries to Alaska, including days at sea (e.g., cruising the inside passage, Glacier Bay, Hubbard Glacier, or/and College Fjord) and port calls (e.g., Juneau, Sitka, Skagway, Ketchikan, Seward, and/or Whittier). All four ships make a port call to Juneau each week, which is where the supplementary sampling was conducted in 2005.

EPA identified anomalous results for certain nitrogen compounds in the 2004 sampling results from two of the four ships sampled: Star and Oosterdam. Specifically, ammonia was either not detected (detection limit = 0.05 mg/L) or detected at very low concentrations (<3 mg/L) in all samples of the influent to and effluent from the treatment systems collected over five consecutive days. EPA believes these results are anomalous for the following reasons:

- Ammonia is produced when proteins are digested and used by the body, and excess ammonia is excreted in urine. Therefore, ammonia is expected to be present in combined graywater and sewage.
- In general, 2004 compliance testing data provided by the U.S. Coast Guard (a total of 25 data points) for treated cruise ship wastewater showed ammonia concentrations generally ranging from 4 mg/L to 110 mg/L, with an average concentration of 31 mg/L; none of the ammonia concentrations were below the detection limit.

- The Alaska Department of Environmental Conservation (ADEC) collected a compliance testing sample during EPA's Star sampling episode. Although the sampling methodology differed (24-hour composite sample for EPA's sample versus grab sample for ADEC's compliance sample), the sampling location and analytical test method were the same. EPA's effluent sampling result for ammonia was below the detection limit (detection limit = 0.05 mg/L), while ADEC's compliance sampling result for ammonia was 68 mg/L.

EPA also identified anomalous total Kjeldahl nitrogen (TKN) data for one of the four ships sampled – Norwegian Star. On this ship, TKN results were unexpectedly low and variable, as compared to results from other cruise ships. TKN concentrations in the influent to and effluent from treatment samples collected over five consecutive days, ordered from lowest to highest concentration, for the four sampled ships are shown below.

Ship	TKN Concentrations (mg/L)	
	Influent to Treatment	**Effluent from Treatment**
Holland America Veendam	60.0, 63.0, 68.0, 80.0, 84.0	11.0, 12.0, 12.0, 28.0, 29.0
Norwegian Star	0.310, 0.760, 3.87, 6.03, 83.7	0.155, 0.760, 0.780, 10.3, 46.3
Island Princess	69.6, 80.2, 84.6, 97.6, 139	27.9, 38.1, 41.1, 42.6, 47.3
Holland America Oosterdam (Sewage/Graywater Treatment System)	182, 192, 192, 197, 200	4.13, 64.0, 68.6, 72.4, 83.2

EPA's review of the ammonia and TKN data for all four sampling episodes did not reveal any obvious errors. The quality control results from each laboratory support the results provided and do not suggest any pervasive problems with the analyses (i.e., matrix spike recoveries and ongoing precision and recovery results were well within the acceptance limits, blanks were free of ammonia and TKN at the levels of interest).

EPA considers ammonia and TKN to be very important analytes in characterizing graywater and sewage generation and treatment onboard cruise vessels. Therefore, EPA conducted the supplementary sampling program described in this report during the 2005 cruise season to collect samples of the influents to and effluents from the treatment systems onboard the same four ships that were sampled in 2004. Five sets of samples were collected from each ship

and analyzed for nitrogen compounds (ammonia, TKN, and nitrate/nitrite). Samples were also analyzed for chemical oxygen demand (COD) and total suspended solids (TSS) to compare these classical pollutant concentrations to those measured during the 2004 cruise season.

Samples were collected in accordance with procedures specified in the *Sampling and Analysis Plan for Nitrogen Compounds Characterization Sampling Episodes 6517 Through 6520, 2005 Alaska Cruise Season* (2005 Sampling SAP). The 2005 Sampling SAP is presented in Appendix C.

Section 2.0 of this report describes the generation, collection, and treatment of graywater and sewage on the four cruise vessels, as well as the sampling point locations used in these sampling episodes. Section 3.0 describes the analyte selection, sample collection methods, and deviations from the 2005 Sampling SAP. Section 4.0 presents and analyzes the analytical data collected during these sampling episodes. Section 5.0 describes the quality assurance and quality control (QA/QC) procedures and results.

2.0 WASTEWATER SYSTEM AND SAMPLING POINTS

This section describes graywater and sewage generation, collection, and treatment on the four cruise vessels, as well as the sample collection points used in these sampling episodes. The sampling episode numbers for each cruise vessel are as follows:

- Veendam – Sampling Episode 6517;
- Star – Sampling Episode 6518;
- Island – Sampling Episode 6519; and
- Oosterdam – Sampling Episode 6520.

Certain information has been removed from this section to protect material for which a claim of confidential business information (CBI) has been made. The confidential version of this report is on file in the confidential portion of the Cruise Ship Rulemaking Record.

2.1 Wastewater Generation and Collection

Each ship's collection, holding, and transfer system (CHT) collects and transfers graywater and sewage generated onboard to the ship's graywater and sewage treatment systems or to overboard discharge. For the purpose of this report, graywater refers to non-sewage wastewaters that are collected by the CHT systems. Each CHT system includes five subsystems, referred to by the ships' crews as the galley, food pulper, accommodations, laundry, and sewage systems. The ship-specific SERs prepared for the 2004 cruise vessel sampling program include additional information regarding each individual CHT system. The four ships differ regarding which of the five CHT subsystems are routed to wastewater treatment and which are routed to double-bottom holding tanks for discharge without treatment outside 12 nautical miles (nm) from shore. The destinations of the CHT subsystems for each ship are listed below:

Ship	Destination of Wastewater: Treated = Treated by the Advanced Wastewater Treatment System Discharged = Discharged Without Treatment Outside 12 nm from Shore				
	Galley	Food Pulper	Accommodations	Laundry	Sewage
Veendam	Treated	Treated	Treated	Treated	Treated
Star	Treated	Discharged	Treated	Treated	Treated
Island	Discharged	Discharged	Treated	Discharged	Treated
Oosterdam	Treated	Discharged	Treated	Treated	Treated

During the sampling episodes, the ships' crews were interviewed to obtain information regarding any changes made to the CHT systems since the 2004 cruise season. No changes were reported.

2.2 Wastewater Treatment

Each of the four sampled ships operates a different advanced wastewater treatment system, and the ship-specific SERs prepared for the 2004 cruise vessel sampling program include detailed descriptions of the wastewater treatment systems. The Veendam is outfitted with a Zenon system, an advanced graywater and sewage treatment system that uses aerobic biological oxidation followed by ultrafiltration and ultraviolet (UV) disinfection. Figure 2-1 is a simplified diagram of the Zenon treatment system. The Star is outfitted with a Scanship system, an advanced graywater and sewage treatment system that uses aerobic biological oxidation followed by dissolved air flotation and UV disinfection. Figure 2-2 is a simplified diagram of the Scanship treatment system. (Figure 2-2 has been modified to prevent disclosure of material for which a claim of CBI has been made.) The Island is outfitted with a Hamworthy system, an advanced graywater and sewage treatment system that uses aerobic biological oxidation followed by ultrafiltration and UV disinfection. Figure 2-3 is a simplified diagram of the Hamworthy treatment system.

The Oosterdam is outfitted with two different ROCHEM systems designed to treat low concentration wastewater and high concentration wastewater separately. The ROCHEM LPRO system (referred to in this report as the ROCHEM graywater treatment system) is an advanced wastewater treatment system that uses low pressure reverse osmosis followed by UV disinfection to treat low concentration wastewater (accommodations and laundry wastewater). The ROCHEM Bio-Filt® System (referred to in this report as the Rochem sewage/graywater treatment system) is an advanced wastewater treatment system that uses aerobic biological oxidation followed by ultrafiltration and UV disinfection to treat high concentration wastewater (sewage, galley wastewater, and membrane concentrate generated by the ROCHEM graywater treatment system). Effluents from the two treatment systems are combined for discharge overboard through a single port. Figure 2-4 is a simplified diagram of

the ROCHEM graywater treatment system and Figure 2-5 is a simplified diagram of the ROCHEM sewage/graywater treatment system.

During the sampling episodes, the ships' crews were interviewed to obtain information regarding any changes made in the treatment systems since the 2004 cruise season. No changes were reported.

2.3 Wastewater and Sample Collection Points

Samples were collected of the influent to and effluent from the treatment systems. Table 2-1 describes the wastewaters sampled, their sampling point locations, and the number of days they were sampled. The influent and effluent sampling point locations are the same as those sampled in 2004, except for the influent to Zenon treatment (Veendam), which was relocated because the original sample tap was prone to plugging (see Section 3.4 for discussion). One sample from each sampling point was collected each week for five consecutive weeks for analysis of nitrogen compounds (ammonia, total Kjeldahl nitrogen, nitrate/nitrite), chemical oxygen demand, and total suspended solids. In addition, three bottle blanks were prepared and analyzed to evaluate possible contamination by the sampling bottles.

Table 2-1. Wastewater and Sampling Point Descriptions, Holland America Veendam, Norwegian Star, Island Princess, and Holland America Oosterdam

Descriptions of wastewaters sampled, sampling point locations, and number of days sampled for the 2005 sampling program (August 1 through August 31, 2005). Note that certain information has been removed from this table to prevent disclosure of CBI.

Wastewater Name	Wastewater Description (a)	Sampling Point # (b)	Sampling Point Description (b)	# of Days Sampled
Veendam - Influent to Zenon Treatment	Combined wastewaters from five collection, holding, and transfer (CHT) subsystems (laundry, accommodations, food pulper, galley, and sewage). A vacuum CHT system conveys sewage from passenger and crew toilets and urinals. The sewage CHT system also conveys wastewater from medical facility sink and floor drains. Wastewater from the laundry, accommodations, food pulper, and galley CHT subsystems culminates in two graywater storage tanks. The sewage CHT subsystem culminates in four sewage collection tanks (one of the sewage collection tanks also receives 14 m^3/day of treated effluent for dilution). Wastewater from the graywater storage tanks and sewage collection tanks mixes in a common line as it flows to the treatment system.	SP-1	Sample tap was installed on the combined graywater and sewage inlet pipe to the bioreactors (after the screens).	5
Veendam - Effluent from Zenon Treatment	Final treated wastewater effluent from the Zenon wastewater treatment system. Effluent is typically continuously discharged overboard. Where discharge is prohibited (e.g., Glacier Bay), wastewater is diverted to storage in double-bottom holding tanks for overboard discharge outside 12 nm from shore.	SP-2	Sample tap was installed on the effluent pipe from UV disinfection, upstream of the diversion valve that directs wastewater to either overboard discharge or to storage in double-bottom holding tanks. Piping distance from the effluent sample tap to the overboard discharge port is 10.5 m.	5
Star - Influent to Scanship Treatment	Combined wastewaters from four CHT subsystems (laundry, accommodations, galley, sewage). Does not include food pulper wastewater, which is discharged without treatment. A vacuum CHT system conveys sewage from passenger and crew toilets and urinals. Gamazyme is added to the toilets as a biological cleaner. Sewage and graywater combine in the graywater and sewage holding tank, which is the first component of the Scanship treatment system.	SP-3	Sample tap was installed on the combined wastewater inlet pipe to the treatment system (before the coarse drum filters).	5

(a) List of wastewater sources may not be comprehensive.
(b) See Figures 2-1 through 2-5 for simplified diagrams of the five wastewater treatment systems indicating the sampling points.

Table 2-1 (Continued)

Wastewater Name	Wastewater Description (a)	Sampling Point # (b)	Sampling Point Description (b)	# of Days Sampled
Star - Effluent to Scanship Treatment	Final treated wastewater effluent from the Scanship wastewater treatment system. Effluent is typically continuously discharged overboard. Where discharge is prohibited (e.g., Glacier Bay), wastewater is diverted to storage in double-bottom holding tanks for overboard discharge outside 12 nm from shore.	SP-4	Sample tap was installed on the overboard discharge pipe following UV disinfection, upstream of the diversion valve that directs wastewater to either overboard discharge or to storage in double-bottom holding tanks.	5
Island - Influent to Hamworthy Treatment	Combined wastewaters from the accommodations and sewage CHT subsystems. Does not include galley, laundry, and food pulper wastewaters, which are discharged at sea without treatment. A vacuum CHT system conveys sewage from passenger and crew toilets and urinals. Sewage CHT system also conveys wastewater from medical facility sink and floor drains. Accommodations CHT system culminates in two holding tanks which are pumped to two wastewater buffer tanks, the first component of the Hamworthy treatment system. The sewage CHT system culminates in four sewage collection tanks. Wastewater from the buffer tanks and sewage collection tanks mixes in a common line as it flows to the screen press component of the Hamworthy treatment system.	SP-5	Sample tap was installed on the combined wastewater inlet pipe to the screen presses.	5
Island - Effluent from Hamworthy Treatment	Final treated wastewater effluent from the Hamworthy wastewater treatment system. Effluent is typically continuously discharged overboard. Where discharge is prohibited (e.g., Glacier Bay), wastewater is diverted to storage in double-bottom holding tanks for discharge overboard outside 12 nm from shore.	SP-6	Sample tap was installed on the effluent pipe from the UV disinfection unit, downstream of the diversion valve that directs wastewater to either overboard discharge or to storage in double-bottom holding tanks. Piping distance from the effluent sample tap to the overboard discharge port is 1m.	5
Oosterdam - Influent to ROCHEM Graywater Treatment System	Combined wastewaters from the accommodations and laundry CHT subsystems. Wastewater from the accommodations and laundry CHT subsystems culminates in three graywater holding tanks, which are the first components of the ROCHEM graywater treatment system.	SP-7	Sample tap was installed on the combined graywater inlet pipe to the treatment system (before the vibratory screen filter).	5

(a) List of wastewater sources may not be comprehensive.
(b) See Figures 2-1 through 2-5 for simplified diagrams of the treatment systems indicating the sampling points.

Table 2-1 (Continued)

Wastewater Name	Wastewater Description (a)	Sampling Point # (b)	Sampling Point Description (b)	# of Days Sampled
Oosterdam - Effluent from ROCHEM Graywater Treatment System	Final treated graywater effluent from the ROCHEM graywater treatment system. Effluent from the ROCHEM graywater treatment system is combined with effluent from the ROCHEM sewage/graywater treatment system and is typically continuously discharged overboard. Where discharge is prohibited, the combined effluent is diverted to storage tanks for overboard discharge outside 12 nm from shore.	SP-8	Sample tap was installed on the outlet pipe from UV disinfection unit, close to the unit and upstream of where the graywater effluent is combined with sewage/graywater effluent for overboard discharge. Piping distance from the graywater effluent sample tap to the overboard discharge port is 30 m.	5
Oosterdam - Influent to ROCHEM Sewage/Graywater Treatment System	Combined wastewaters from the galley and sewage CHT subsystems. Also includes reverse osmosis concentrate from the ROCHEM graywater treatment system. Wastewater from the galley and sewage CHT subsystems culminates in two buffer tanks, the first component of the ROCHEM sewage/graywater treatment system. Reverse osmosis concentrate from the ROCHEM graywater treatment system is also routed to the buffer tanks. Wastewater is pumped between the two buffer tanks to produce a homogeneous influent to the treatment system.	SP-9	Sample tap was installed on the recirculation loop that mixes wastewater from the two buffer tanks.	5
Oosterdam - Effluent from ROCHEM Sewage/Graywater Treatment System	Final treated sewage/graywater effluent from the ROCHEM sewage/graywater treatment system. Effluent from the ROCHEM graywater treatment system is combined with effluent from the ROCHEM sewage/graywater treatment system and is typically continuously discharged overboard. Where discharge is prohibited, the combined wastewater is diverted to storage tanks for overboard discharge outside 12 nm from shore.	SP-10	Sample tap was installed on the outlet pipe from the UV disinfection unit, close to the unit and upstream of where the sewage/graywater effluent is combined with graywater effluent for overboard discharge. Piping distance from the sewage/graywater effluent sample tap to the overboard discharge port is 45 to 50 m.	5
Oosterdam - Final Combined Treated Effluent	Combined treated effluent from the graywater and the sewage/graywater treatment systems. Combined effluent is typically continuously discharged overboard. Where discharge is prohibited, the combined wastewater is diverted to storage tanks for overboard discharge outside 12 nm from shore.	SP-11	Sample tap was installed on the overboard discharge line, downstream of where graywater and sewage/graywater effluents are combined and downstream of the diversion valve that directs wastewater to either overboard discharge or storage in double-bottom holding tanks. Piping distance from the combined effluent sample tap to the overboard discharge port is <1 m.	5

(a) List of wastewater sources may not be comprehensive.
(b) See Figures 2-1 through 2-5 for simplified diagrams of the treatment systems indicating the sampling points.

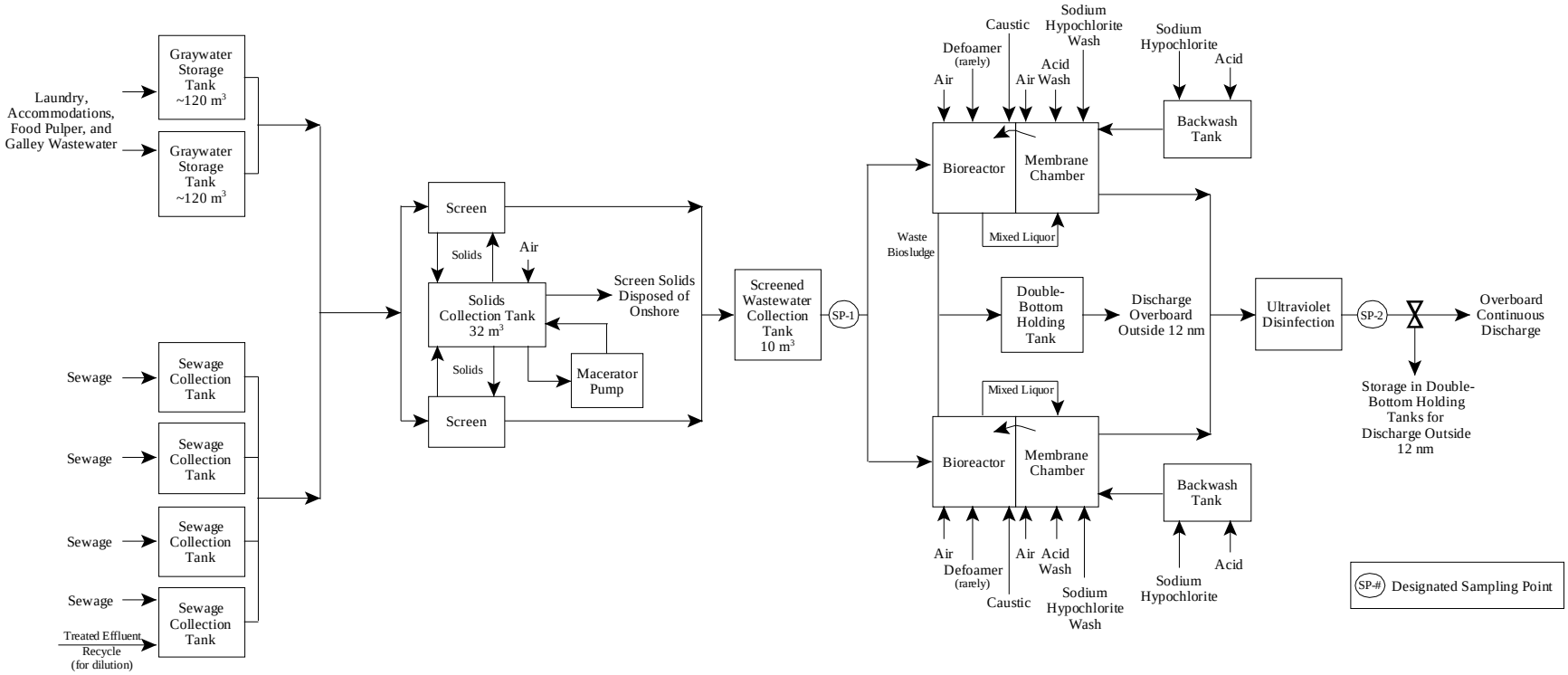

Figure 2-1. Zenon Treatment System, Holland America Veendam

Simplified diagram of the Holland America Veendam Zenon treatment system. See Table 2-1 for a list of wastewater streams in each sampled wastewater.

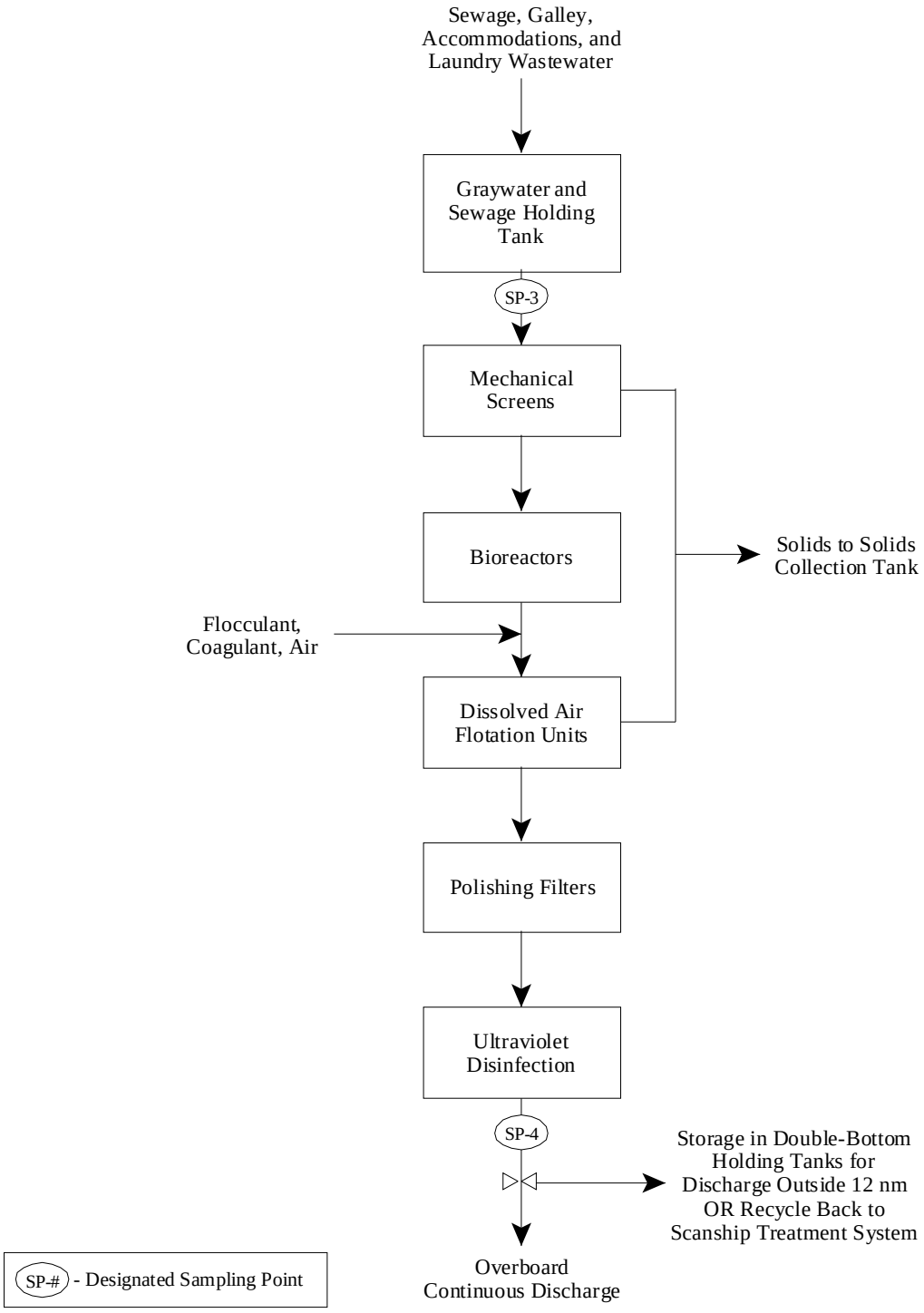

Figure 2-2. Scanship Treatment System, Norwegian Star

Simplified diagram of the Norwegian Star Scanship treatment system. See Table 2-1 for a list of wastewater streams in each sampled stream. Note that this diagram has been modified to prevent disclosure of material for which a claim of CBI has been made.

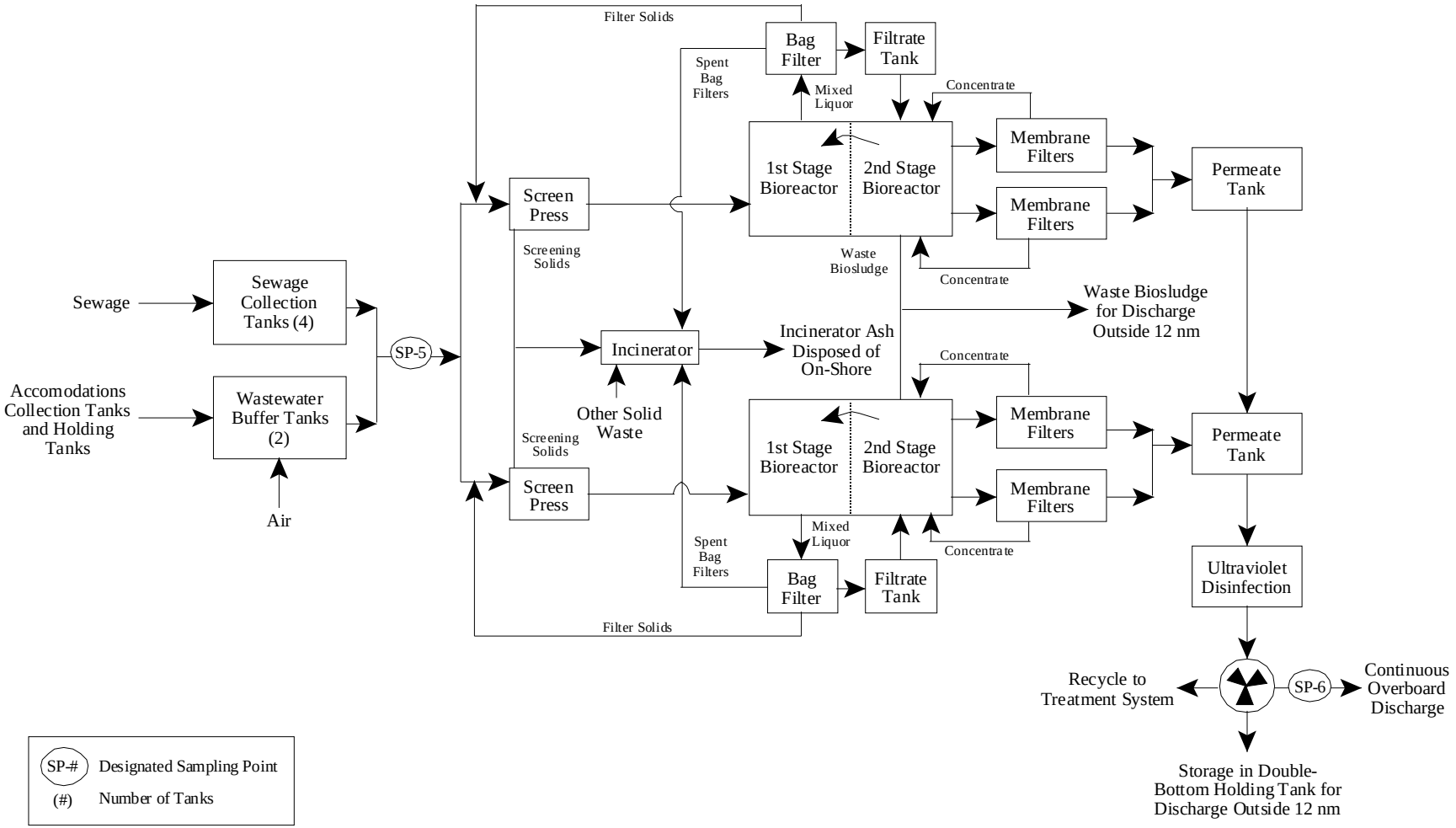

Figure 2-3. Hamworthy Treatment System, Island Princess

Simplified diagram of the Island Princess Hamworthy treatment system. See Table 2-1 for a list of wastewater streams in each sampled stream.

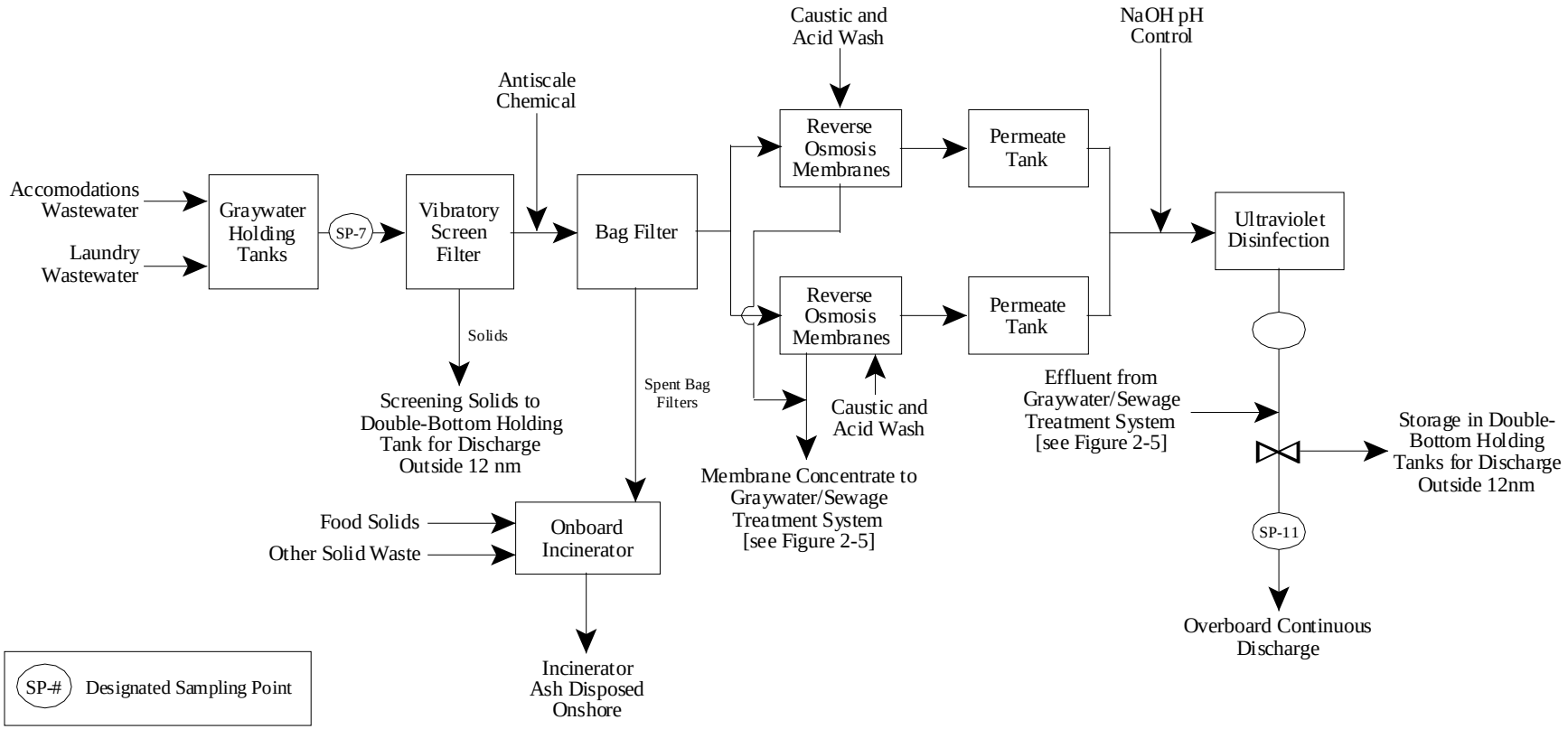

Figure 2-4. ROCHEM Graywater Treatment System, Holland America Oosterdam

Simplified diagram of the Holland America Oosterdam ROCHEM graywater treatment system. See Table 2-1 for a list of wastewater streams in each sampled stream.

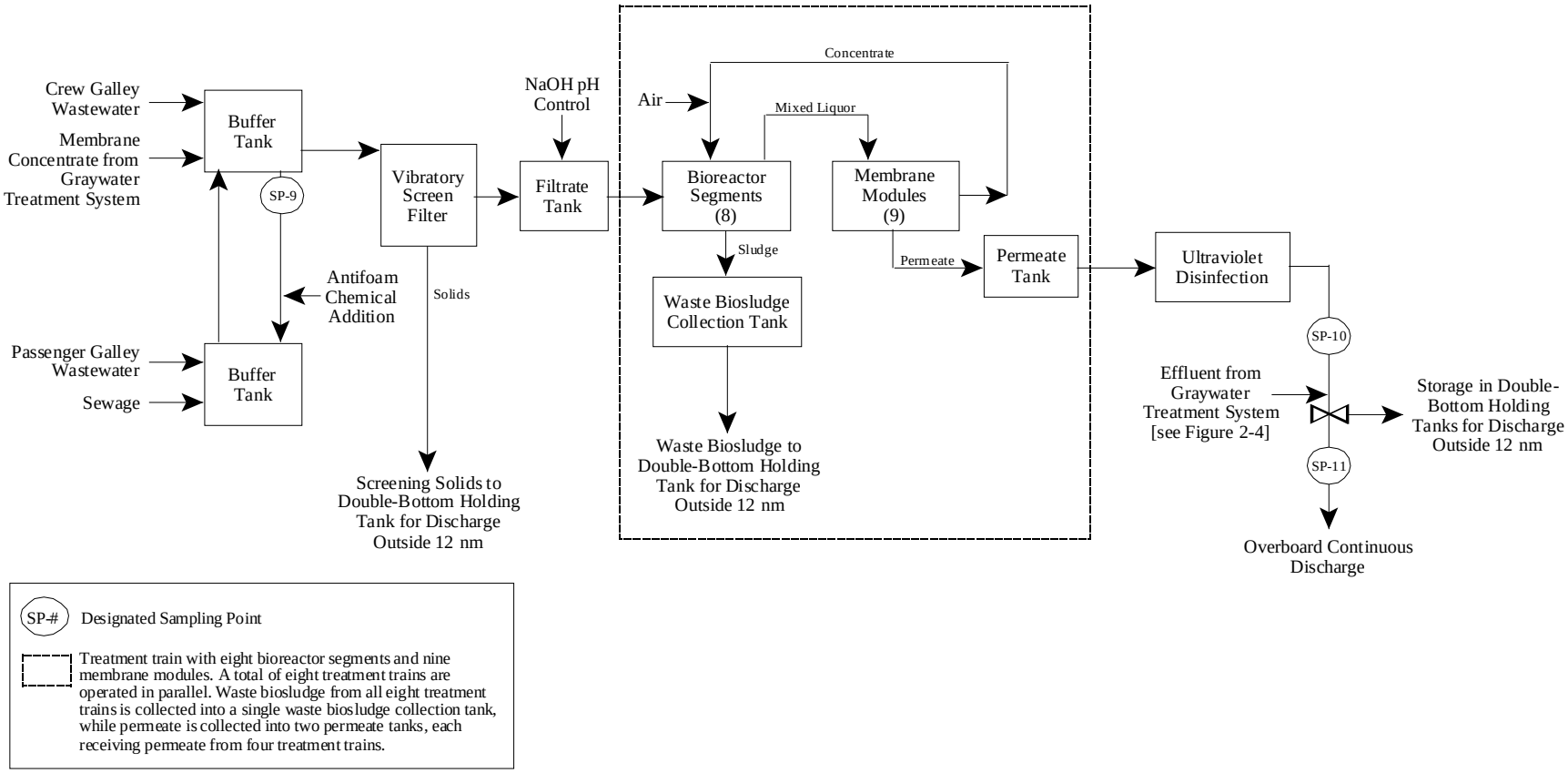

Figure 2-5. ROCHEM Sewage/Graywater Treatment System, Holland America Oosterdam

Simplified diagram of the Holland America Oosterdam ROCHEM sewage/graywater treatment system. See Table 2-1 for a list of wastewater streams in each sampled stream.

3.0 SAMPLE COLLECTION

This section describes the sample collection and analysis methods and deviations from the *Sampling and Analysis Plan for Nitrogen Compounds Characterization Sampling Episodes 6517 through 6520, 2005 Alaska Cruise Season* (2005 Sampling SAP; Appendix C). A more detailed explanation of the sampling methodologies, analytes and analytical methods, sampling frequency and duration, schedule, and logistics that were followed during sampling can be found in Section 3.0 of the 2005 Sampling SAP.

3.1 Pre-Sampling Activities

Visits to each of the four ships were conducted during the week prior to the start of the sampling episode to establish ship contacts, communications, and safety and emergency procedure, and to inspect installation of required sampling ports and associate fittings.

3.2 Sample Collection and Analysis Methodology

One grab composite sample was collected from each sampling point each week for five consecutive weeks during each ship's weekly port call to Juneau, Alaska. Grab composite samples are manual grab samples composited in the field to produce a single sample for analysis. Each grab composite sample consisted of 4 grab samples collected over approximately 7 hours. Specifically, the sampling team filled one-fourth of the sample containers when they collected each of the four samples, resulting in a full sample container at the end of each sampling period. Sample containers were filled directly from the sample taps. Table 3-1 describes the analyte groups and lists the analytical methods used.

Each time a grab sample was taken, another separate sample was placed in a separate container for field measurement of pH, temperature, and ammonium. Temperature and pH were measured immediately at the sampling point, while ammonium was measured at the sample staging area onboard. See Table 3-2 for equipment used for these measurements. Field measurements for temperature and pH were taken as a simple means of assessing the real-time variability of wastewater characteristics during the sampling periods. Ammonium measurements

were taken to inform the laboratory of the anticipated ammonia and TKN concentrations in the wastewater samples.

It is important to note that this sampling methodology differed from that used during the 2004 sampling program. For that program, composite samples were collected over a 24-hour period for five consecutive days, and the resulting samples represented all ship operating conditions (e.g., day versus night, in port versus at sea). In addition, the composite samples for the 2004 sampling program were flow-weighted composite samples; grab samples were automatically collected each time a fixed quantity of wastewater passed through the wastewater pipe, resulting in a composite sample consisting of a total of 75 to 150 grab samples per 24-hour composite period.

EPA recognized that the 2005 sampling methodology may result in samples less representative of untreated and treated wastewater than the 2004 sampling methodology. Factors affecting the representativeness of the 2005 samples compared to the 2004 samples are: (1) composite periods of 7 hours (in port) versus 24 hours (in port and at sea), (2) composite samples weighted by time versus flow, and (3) composite samples composed of 4 grab samples versus 75 to 150 grab samples. EPA believed the samples would be sufficiently representative to meet the needs of this program for three reasons. First, while the waste streams sampled in 2004 were variable, EPA did not identify significant differences in wastewater characteristics depending on whether the vessels were at sea versus in port. Second, EPA did not identify significant differences in wastewater characteristics depending on time of day, based on a comparison of the results of pathogen indicator grab samples collected at night versus those collected during the day. Third, the wastewater flow profile for the influent to and effluent from treatment is relatively constant, particularly during daytime hours, due to continuous graywater and sewage generation throughout the ship and the wastewater holding time (equalization) provided by the CHT and wastewater treatment systems. The analyses that support these conclusions are included in the Cruise Ship Rulemaking Record.

However, EPA underestimated the impact of the reduction in the number of grab samples on the representativeness of the composite samples, particularly for the influent to treatment system samples. In general, the composition of an individual grab sample of the

influent to the treatment is primarily dictated by the pump cycles of the collection tanks for the sewage and graywater. Individual grab samples of the influent to treatment can contain highly variably proportions of sewage and graywater, depending on which pump(s) were operating during the time of grab sample collection. Highly variable proportions of sewage and graywater in influent to treatment grab samples where particularly evident for the Island Princess influent to treatment sampling point. At this sampling location, some individual grab samples appeared to be composed solely of graywater (as evidenced by clear samples with little suspended solids and low or nondetect ammonium levels, see Appendix A) and others appeared to be composed solely of sewage (as evidenced by highly colored and turbid samples with relatively high ammonium levels, see Appendix A). Collection of representative samples at this sampling location can be assured only by compositing a large number of grab samples collected throughout a prolonged sampling period, as was the case during the 2004 sampling program. Data users should consider limitations of the representativeness of the influent to treatment sample results in general, and specifically for the Island Princess influent to Hamworthy treatment sample results.

There is significantly less concern regarding the representativeness of the effluent from treatment samples because in general the quality of the effluent is far less variable, primarily due to the wastewater equalization that occurs in the wastewater treatment systems. Wastewater equalization refers to wastewater holding to reduce variability in terms of both flow and wastewater characteristics. This is supported by the relatively consistent physical characteristics and field measurements for effluent from treatment grab samples (see Appendix A). However, for those wastewater treatment systems that are composed of parallel treatment trains that culminate in permeate tanks (the Hamworthy and ROCHEM systems shown in Figures 2-3 through 2-5), the composition of an individual grab sample of the effluent from treatment is dictated by the pump cycles of the permeate tanks. Individual grab samples of the effluent from treatment can contain highly variable proportions of effluent from individual treatment trains. Data users should consider possible limitations of the representativeness of the effluent from treatment sample results for these systems.

3.3 Quality Assurance/Quality Control

Duplicate samples were collected for quality assurance and quality control. Results for duplicate samples were averaged. See Section 5.2.2 and Table 5-2 for details on duplicate sampling. Other field quality control samples prepared for this sampling episode include bottle blanks and performance evaluation samples, which are discussed in Sections 5.2.1 and 5.2.3, respectively.

3.4 Deviations from the Sampling and Analysis Plan

The sampling episode proceeded as specified in the 2005 Sampling SAP with one deviation for the Holland America Veendam. The sampling location for the Veendam influent to Zenon treatment sampling point (SP-1) was moved from before the screens to after the screened wastewater collection tank because the sample tap located before the screens was prone to plugging (see Figure 2-1 for the revised sampling point location). This change in sampling location, which occurred following the collection of the first grab sample on the first day of sampling, is expected to result in reduced TSS concentrations (because some TSS would be expected to be removed by the screens) and reduced wastewater variability (because of wastewater equalization provided by the screened wastewater collection tank).

Table 3-1. Analytes and Analytical Methods, Holland America Veendam, Norwegian Star, Island Princess, and Holland America Oosterdam

Analytes	Analytical Method Number
Ammonia as Nitrogen (NH3-N)	350.3
Chemical Oxygen Demand (COD)	410.4
Nitrate/Nitrite (NO3-N + NO2-N)	300.0
Total Kjeldahl Nitrogen (TKN)	351.3
Total Suspended Solids (TSS)	160.2

Table 3-2. Field Measurement Equipment, Holland America Veendam, Norwegian Star, Island Princess, and Holland America Oosterdam

Parameter	Measured by:
pH	Digital pH meter (Oakton, Cat. No. WD-35624-84)
Temperature	Digital thermometer (Fisher Scientific, Cat. No. S407993)
Ammonium	Ammonium test strips (Gallard-Schlesinger, Quantofix® Test Strips, Ammonium, Cat. No. 91315)

4.0 RESULTS AND DISCUSSION

This section presents the data collected during this sampling program. Section 4.1 presents the analytical results and discussion for the influents to the treatment systems, and Section 4.2 presents the analytical results and discussion for the effluents from the treatment systems. Section 4.3 describes the performance of the treatment systems. Finally, Section 4.4 compares the analytical results for the 2004 and 2005 sampling programs. Analytical results for field measurements performed onboard are presented in Appendix A.

4.1 Influents to Treatment Systems

Table 4-1 presents analytical results for the influents to the five sampled wastewater treatment systems, which were sampled as grab composite samples one day each week for five weeks. Ammonia, chemical oxygen demand (COD), total Kjeldahl Nitrogen (TKN), and total suspended solids (TSS) were detected in all influent to treatment samples. Nitrate/nitrite was not detected in any influent to treatment samples for the Star or Island treatment systems or for the Oosterdam graywater treatment system. Nitrate/nitrite was detected in most influent to treatment samples for the Veendam treatment system and the Oosterdam sewage/graywater treatment systems.

Wastewater conservation practices used onboard, such as use of vacuum toilets, result in highly concentrated wastewater. Chart 1 compares the influent to the five wastewater treatment systems to typical domestic wastewater for selected analytes.

Chart 1. Comparison of Influents to Treatment Systems to Untreated Domestic Wastewater

Analyte/Wastewater	Influent to Treatment Systems (mg/L)					
	Veendam Zenon Treatment System	Star Scanship Treatment System	Island Hamworthy Treatment System (a)	Oosterdam ROCHEM Graywater Treatment System	Oosterdam ROCHEM Sewage/Graywater Treatment System	Untreated Domestic Wastewater (b)
Chemical Oxygen Demand (COD)	934 to 1,270	645 to 1,490	194 to 3,640	188 to 305	1,850 to 2,280	250 to 1,000
Nitrate/Nitrite	ND(0.500) to 1.47	ND(0.200) to ND(0.500)	ND(0.500) to ND(1.00)	ND(0.200) to ND(0.500)	ND(0.500) to 0.999	0
Total Suspended Solids (TSS)	193 to 392	103 to 588	37.6 to 1,920	27.9 to 48.7	275 to 853	100 to 350
Ammonia	54.0 to 76.0	22.0 to 80.0	4.90 to 390	2.80 to 6.80	30.0 to 150	12 to 50
Total Kjeldahl Nitrogen (TKN)	59.0 to 95.2	29.8 to 85.0	9.95 to 496	6.68 to 11.1	167 to 204	20 to 85 (c)

(a) Sample results may not be representative of the Island influent to Hamworthy treatment (see Section 3.2).
(b) Source: Metcalf & Eddy, *Wastewater Engineering*, Third Edition, 1991.
(c) Calculated as organic nitrogen plus free ammonia.

4.2 Effluents from the Treatment Systems

Table 4-2 presents analytical results for the effluents from the five sampled wastewater treatment systems, which were sampled as grab composite samples one day each week for five weeks. Ammonia, TKN, and COD were detected in almost all effluent from treatment system samples for all five ships. Nitrate/nitrite was not detected in any effluent from treatment samples for the Veendam or Oosterdam graywater treatment systems and was detected in only one sample for the Star treatment system. Nitrate/nitrite was detected in most effluents from treatment samples for the Island and Oosterdam sewage/graywater treatment system (and the corresponding Oosterdam final combined treated effluent). TSS generally was not detected in effluent from treatment samples, except for the effluent from the Star Scanship treatment system. Chart 2 shows that TSS concentrations in the effluent from the treatment systems are lower than EPA's standards for secondary treatment.

Chart 2. Total Suspended Solids (TSS) Comparison of Effluent from the Treatment Systems to Secondary Treatment Standards

Treatment Systems	Average Effluent from the Treatment Systems	Secondary Treatment Standards (a)
Veendam - Zenon Treatment System	ND(4.20) mg/L	45 mg/L
Star - Scanship Treatment System	<7.32 mg/L	45 mg/L
Island - Hamworthy Treatment System	ND(4.00) mg/L	45 mg/L
Oosterdam – Final Combined Treated Effluent	ND(4.00) mg/L	45 mg/L

(a) 40 CFR 133.102 Secondary Treatment Regulations, 7-day average.
ND - Not detected (number in parentheses is detection limit).

4.3 Wastewater Treatment System Performance: Comparison of Influent to Treatment Systems and Effluent from Treatment Systems

All five wastewater treatment systems successfully removed most chemical oxygen demand (COD) (>82%; Table 4-3 and Chart 3) and total suspended solids (TSS) (>89%; Table 4-3 and Chart 3). The systems also removed some ammonia and TKN (measures both ammonia and organic form of nitrogen), while nitrate/nitrite levels remained relatively unchanged (Table 4-3 and Chart 3). Nitrogen removed by the treatment systems is likely taken up by the microorganisms in the bioreactors and removed from the systems in the waste biosludge. It is unlikely that nitrogen is removed by nitrification (the mechanism of ammonia biodegradation) as nitrification would have resulted in an increase in nitrate/nitrite concentration, but these levels remained relatively unchanged.

Chart 3. Comparison of Influents to Treatment Systems and Effluent from Treatment Systems

Treatment Systems	% Removal				
	Chemical Oxygen Demand (COD)	Nitrate/Nitrite	Total Suspended Solids (TSS)	Ammonia	Total Kjeldahl Nitrogen (TKN)
Veendam - Zenon Treatment System	96	>67	>98	86	>89
Star - Scanship Treatment System	96	NC	>97	30	49
Island Hamworthy Treatment System	94	NC	>99	85	87
Oosterdam - ROCHEM Graywater Treatment System	>82	NC	>89	58	68
Oosterdam - ROCHEM Sewage/Graywater Treatment System	96	NC	>99	53	72

NC - Percent removal not calculated because the effluent concentration was greater than the influent concentration, or the pollutant was not detected in the influent sample.
> - Indicates a minimum level of removal.

4.4 Comparison of Analytical Data from 2004 and 2005 Sampling Programs

Table 4-4 compares the average influent to and effluent from treatment system concentrations and percent removals for nitrogen compounds, COD, and TSS for the 2004 and 2005 cruise seasons.

As discussed in Section 1.0, EPA conducted the 2005 sampling program to inform and supplement anomalous nondetect ammonia results for the Star and Oosterdam for the 2004 sampling program. 2004 TKN results for the Star were also believed to be anomalous. In contrast to 2004, ammonia and TKN were detected in all influent and effluent samples in 2005 and were found at levels consistent with those from other data sources (ADEC) and from the literature. For the Veendam, ammonia and TKN concentrations appear to have decreased from 2004 to 2005, while treatment performance (percent removals) appears to have improved. For the Island, average ammonia and TKN concentrations in the influent to treatment appear to have increased significantly from 2004 to 2005 (with a corresponding improvement in treatment performance). These differences are likely caused by the differing sampling methodologies used for these two sampling programs (see Section 3.2).

Samples from 2005 were also analyzed for COD and TSS to compare these classical pollutants to those measured during the 2004 cruise season. Results for the two sampling programs are expected to be similar as interviews with the ships' crews indicated that there were no significant changes in the numbers of passengers carried and operation or performance of the CHT and wastewater treatment systems from 2004 to 2005. While the average influent and effluent COD and TSS concentrations may have increased or decreased somewhat from 2004 to 2005 for the five treatment systems on these four ships, treatment performance for these analytes was similar. In particular, there was no significant difference in the effluent COD measurements between 2004 and 2005, and the TSS measurements in the effluent were mostly below detection in both years.

Table 4-1. Influent to Treatment System Analytical Results for Holland America Veendam, Norwegian Star, Island Princess, and Holland America Oosterdam

Analytical results for the influent to the treatment systems for the four vessels. Influent to treatment system samples were collected during each ship's port call to Juneau each week for five consecutive weeks; see Section 3.2 for the sample collection methodology. Figures 2-1 through 2-5 identify the sampling locations. Average influent to treatment concentrations determined from the weekly results.

Analyte	Unit	Week 1	Week 2	Week 3	Week 4	Week 5	Average
Holland America Veendam - Influent to Zenon Treatment (SP-1) (a)							
Ammonia As Nitrogen (NH3-N)	mg/L	41.0	54.0	76.0	55.0	54.0	56.0
Chemical Oxygen Demand (COD)	mg/L	1,110	1,190	1,150	934	1,270	1,130
Nitrate/Nitrite (NO3-N + NO2-N)	mg/L	0.920	0.561	1.47	0.431	ND(0.500)	<0.776
Total Kjeldahl Nitrogen (TKN)	mg/L	59.0	76.6	95.2	75.2	90.0	79.2
Total Suspended Solids (TSS)	mg/L	193	288	338	200	392	282
Norwegian Star - Influent to Scanship Treatment (SP-3) (a)							
Ammonia As Nitrogen (NH3-N)	mg/L	22.0	80.0	57.0	25.0	48.0	46.4
Chemical Oxygen Demand (COD)	mg/L	645	839	830	740	1,490	909
Nitrate/Nitrite (NO3-N + NO2-N)	mg/L	ND(0.500)	ND(0.200)	ND(0.500)	ND(0.300)	ND(0.500)	ND(0.400)
Total Kjeldahl Nitrogen (TKN)	mg/L	29.8	85.0	74.6	39.0	81.6	62.0
Total Suspended Solids (TSS)	mg/L	103	230	249	166	588	267
Island Princess - Influent to Hamworthy Treatment (SP-5) (a) (b)							
Ammonia As Nitrogen (NH3-N)	mg/L	270	59.0	390	380	4.90	221
Chemical Oxygen Demand (COD)	mg/L	2,420	489	3,640	2,900	194	1,930
Nitrate/Nitrite (NO3-N + NO2-N)	mg/L	ND(0.500)	ND(1.00)	ND(0.500)	ND(1.00)	ND(1.00)	ND(0.800)
Total Kjeldahl Nitrogen (TKN)	mg/L	280	74.0	488	496	9.95	270
Total Suspended Solids (TSS)	mg/L	920	238	1,920	1,550	37.6	933

(a) Sampling point location; see Figures 2-1 through 2-5.
(b) Sample results may not be representative of the Island influent to Hamworthy treatment (see Section 3.2).
ND – Not detected (number in parentheses is detection limit).
< -Average result includes at least one non-detect value (calculation uses detection limits for nondetected and results.)

Table 4-1 (Continued)

Analyte	Unit	Week 1	Week 2	Week 3	Week 4	Week 5	Average
Holland America Oosterdam - Influent to ROCHEM Graywater Treatment (SP-7) (a)							
Ammonia As Nitrogen (NH3-N)	mg/L	6.80	5.10	3.40	4.60	2.80	4.54
Chemical Oxygen Demand (COD)	mg/L	305	270	215	290	188	254
Nitrate/Nitrite (NO3-N + NO2-N)	mg/L	ND(0.500)	ND(0.200)	ND(0.200)	ND(0.200)	ND(0.200)	ND(0.260)
Total Kjeldahl Nitrogen (TKN)	mg/L	11.1	10.6	8.81	11.1	6.68	9.66
Total Suspended Solids (TSS)	mg/L	30.1	43.8	27.9	48.7	28.1	35.7
Holland America Oosterdam - Influent to ROCHEM Sewage/Graywater Treatment (SP-9) (a)							
Ammonia As Nitrogen (NH3-N)	mg/L	150	130	120	30.0	97.0	105
Chemical Oxygen Demand (COD)	mg/L	2,280	2,180	1,850	1,960	2,260	2,110
Nitrate/Nitrite (NO3-N + NO2-N)	mg/L	0.999	0.665	ND(0.500)	0.665	ND(0.500)	<0.666
Total Kjeldahl Nitrogen (TKN)	mg/L	204	202	167	176	169	184
Total Suspended Solids (TSS)	mg/L	848	598	766	275	853	668

(a) Sampling point location; see Figures 2-1 through 2-5.
(b) Sample results may not be representative of the Island influent to Hamworthy treatment (see Section 3.2).
ND – Not detected (number in parentheses is detection limit).
< -Average result includes at least one non-detect value (calculation uses detection limits for nondetected and results.)

Table 4-2. Effluent from Treatment System Analytical Results for Holland America Veendam, Norwegian Star, Island Princess, and Holland America Oosterdam

Analytical results for the effluent from the treatment systems for the four vessels. Effluent from treatment system samples were collected during each ship's port call to Juneau each week for five consecutive weeks; see Section 3.2 for the sample collection methodology. Figures 2-1 through 2-5 identify the sampling locations. Average effluent to treatment concentrations determined from the weekly results.

Analyte	Unit	Week 1	Week 2	Week 3	Week 4	Week 5	Average
Holland America Veendam - Effluent from Zenon Treatment (SP-2) (a)							
Ammonia As Nitrogen (NH3-N)	mg/L	17.0	2.80	9.80	0.0990	8.20	7.58
Chemical Oxygen Demand (COD)	mg/L	57.0	62.0	50.0	36.0	47.0	50.4
Nitrate/Nitrite (NO3-N + NO2-N)	mg/L	ND(0.500)	ND(0.200)	ND(0.200)	ND(0.200)	ND(0.200)	ND(0.260)
Total Kjeldahl Nitrogen (TKN)	mg/L	15.6	5.18	13.1	< 1.03	9.03	<8.81
Total Suspended Solids (TSS)	mg/L	ND(4.00)	ND(5.00)	ND(4.00)	ND(4.00)	ND(4.00)	ND(4.20)
Norwegian Star - Effluent from Scanship Treatment (SP-4) (a)							
Ammonia As Nitrogen (NH3-N)	mg/L	31.5	26.0	38.0	29.0	37.0	32.3
Chemical Oxygen Demand (COD)	mg/L	35.0	43.0	45.0	37.0	36.0	39.2
Nitrate/Nitrite (NO3-N + NO2-N)	mg/L	1.38	ND(0.200)	ND(0.200)	ND(0.300)	ND(0.200)	<0.456
Total Kjeldahl Nitrogen (TKN)	mg/L	27.4	26.7	37.8	31.6	33.5	31.4
Total Suspended Solids (TSS)	mg/L	ND(4.00)	19.5	ND(4.00)	ND(4.00)	5.10	<7.32
Island Princess - Effluent from Hamworthy Treatment (SP-6) (a)							
Ammonia As Nitrogen (NH3-N)	mg/L	29.0	24.0	24.0	44.0	47.0	33.6
Chemical Oxygen Demand (COD)	mg/L	89.0	89.0	106	74.0	214	114
Nitrate/Nitrite (NO3-N + NO2-N)	mg/L	9.02	10.6	0.525	5.38	ND(0.500)	<5.21
Total Kjeldahl Nitrogen (TKN)	mg/L	26.7	25.1	26.4	42.0	52.9	34.6
Total Suspended Solids (TSS)	mg/L	ND(4.00)	ND(4.00)	ND(4.00)	ND(4.00)	ND(4.00)	ND(4.00)

(a) Sampling point location; see Figures 2-1 through 2-5.
ND – Not detected (number in parentheses is detection limit).
< -Average result includes at least one non-detect value (calculation uses detection limits for nondetected results.)

Table 4-2 (Continued)

Analyte	Unit	Week 1	Week 2	Week 3	Week 4	Week 5	Average
Holland America Oosterdam - Effluent from ROCHEM Graywater Treatment (SP-8) (a)							
Ammonia As Nitrogen (NH3-N)	mg/L	4.10	1.80	1.40	1.60	0.720	1.92
Chemical Oxygen Demand (COD)	mg/L	106	39.0	26.0	34.0	ND(20.0)	<45.0
Nitrate/Nitrite (NO3-N + NO2-N)	mg/L	ND(0.500)	ND(0.200)	ND(0.200)	ND(0.200)	ND(0.200)	ND(0.200)
Total Kjeldahl Nitrogen (TKN)	mg/L	5.64	3.31	2.20	2.49	1.83	3.09
Total Suspended Solids (TSS)	mg/L	ND(4.00)	ND(4.00)	ND(4.00)	ND(4.00)	ND(4.00)	ND(4.00)
Holland America Oosterdam - Effluent from ROCHEM Sewage/Graywater Treatment (SP-10) (a)							
Ammonia As Nitrogen (NH3-N)	mg/L	38.0	73.0	51.5	41.0	45.0	49.7
Chemical Oxygen Demand (COD)	mg/L	62.0	96.0	80.0	93.0	85.0	83.2
Nitrate/Nitrite (NO3-N + NO2-N)	mg/L	1.15	0.845	5.43	ND(0.500)	ND(0.500)	<1.69
Total Kjeldahl Nitrogen (TKN)	mg/L	36.8	74.6	52.0	40.6	56.4	52.1
Total Suspended Solids (TSS)	mg/L	ND(4.00)	ND(4.00)	ND(4.00)	ND(4.00)	ND(4.00)	ND(4.00)
Holland America Oosterdam – Final Combined Treated Effluent (SP-11) (a)							
Ammonia As Nitrogen (NH3-N)	mg/L	27.0	20.0	17.0	16.0	31.0	22.2
Chemical Oxygen Demand (COD)	mg/L	82.0	58.0	41.0	69.5	60.0	62.1
Nitrate/Nitrite (NO3-N + NO2-N)	mg/L	0.592	0.286	1.79	ND(0.500)	ND(0.500)	<0.734
Total Kjeldahl Nitrogen (TKN)	mg/L	25.4	20.8	17.1	16.0	34.2	22.7
Total Suspended Solids (TSS)	mg/L	ND(4.00)	ND(4.00)	ND(4.00)	ND(4.00)	ND(4.00)	ND(4.00)

(a) Sampling point location; Figures 2-1 through 2-5 and Table 2-1.
ND – Not detected (number in parentheses is detection limit).
< -Average result includes at least one non-detect value (calculation uses detection limits for nondetected results.)

Table 4-3. Wastewater Treatment System: Performance Data for Holland America Veendam, Norwegian Star, Island Princess, and Holland America Oosterdam

Performance data for the wastewater treatment systems for the four vessels. Range and average analyte concentrations were determined from the weekly results presented in Tables 4-1 and 4-2, the influents to and effluents from treatment sampling points, respectively. Percent removals were calculated using the average influent and effluent analyte concentrations.

Analyte	Unit	Average Influent to Treatment Concentration	Influent to Treatment Concentration Range	Average Effluent from Treatment Concentration	Effluent from Treatment Concentration Range	Percent Removal
Holland America Veendam - Zenon Treatment System						
Ammonia As Nitrogen (NH3-N)	mg/L	56.0	41.0 - 76.0	7.58	0.0990 - 17.0	86
Chemical Oxygen Demand (COD)	mg/L	1,130	934 - 1,270	50.4	36.0 - 62.0	96
Nitrate/Nitrite (NO3-N + NO2-N)	mg/L	<0.776	ND(0.500) - 1.47	ND(0.260)	ND(0.200) - ND(0.500)	> 67
Total Kjeldahl Nitrogen (TKN)	mg/L	79.2	59.0 - 95.2	<8.81	<1.03 - 15.7	> 89
Total Suspended Solids (TSS)	mg/L	282	193 - 392	ND(4.20)	ND(4.00) - ND(5.00)	> 98
Norwegian Star - Scanship Treatment System						
Ammonia As Nitrogen (NH3-N)	mg/L	46.4 (a)	22.0 - 80.0	32.3	26.0 - 38.0	30
Chemical Oxygen Demand (COD)	mg/L	909 (a)	645 - 1,490	39.2	35.0 - 45.0	96
Nitrate/Nitrite (NO3-N + NO2-N)	mg/L	ND(0.400) (a)	ND(0.200) - ND(0.500)	<0.456	ND(0.200) - 1.38	NC
Total Kjeldahl Nitrogen (TKN)	mg/L	62.0 (a)	29.8 - 85.0	31.4	26.7 - 37.8	49
Total Suspended Solids (TSS)	mg/L	267 (a)	103 – 588	<7.32	ND(4.00) - 19.5	> 97

(a) Sample results may not be representative of the Island influent to Hamworthy treatment system (see Section 3.2).
NC - Percent removal not calculated because the effluent concentration was greater than the influent concentration, or the pollutant was not detected in the influent sample.
ND - Not detected (number in parentheses is detection limit).
< - Average result reported includes at least one non-detect value (calculation uses detection limits for non-detect results).
> - Indicates a minimum level of removal.

Table 4-3 (Continued)

Analyte	Unit	Average Influent to Treatment Concentration	Influent to Treatment Concentration Range	Average Effluent from Treatment Concentration	Effluent from Treatment Concentration Range	Percent Removal
Island Princess - Hamworthy Treatment System						
Ammonia As Nitrogen (NH3-N)	mg/L	221	4.90 – 390 (a)	33.6	24.0 - 47.0	85
Chemical Oxygen Demand (COD)	mg/L	1,930	194 - 3,640 (a)	114	74.0 - 214	94
Nitrate/Nitrite (NO3-N + NO2-N)	mg/L	ND(0.800)	ND(0.500) - ND(1.00) (a)	<5.21	ND(0.500) - 10.6	NC
Total Kjeldahl Nitrogen (TKN)	mg/L	270	9.95 – 496 (a)	34.6	25.1 - 52.9	87
Total Suspended Solids (TSS)	mg/L	933	37.6 - 1,920 (a)	ND(4.00)	ND(4.00)	> 99
Holland America Oosterdam - ROCHEM Graywater Treatment System						
Ammonia As Nitrogen (NH3-N)	mg/L	4.54	2.80 - 6.80	1.92	0.720 - 4.10	58
Chemical Oxygen Demand (COD)	mg/L	254	188 - 305	<45.0	ND(20.0) - 106	> 82
Nitrate/Nitrite (NO3-N + NO2-N)	mg/L	ND(0.260)	ND(0.200) - ND(0.500)	ND(0.260)	ND(0.200) – ND(0.500)	NC
Total Kjeldahl Nitrogen (TKN)	mg/L	9.66	6.68 - 11.1	3.09	1.83 - 5.64	68
Total Suspended Solids (TSS)	mg/L	35.7	27.9 - 48.7	ND(4.00)	ND(4.00)	> 89
Holland America Oosterdam - ROCHEM Sewage/Graywater Treatment System						
Ammonia As Nitrogen (NH3-N)	mg/L	105	30.0 - 150	49.7	38.0 - 73.0	53
Chemical Oxygen Demand (COD)	mg/L	2,110	1,850 - 2,280	83.2	62.0 - 96.0	96
Nitrate/Nitrite (NO3-N + NO2-N)	mg/L	<0.666	ND(0.500) - 0.999	<1.69	ND(0.500) - 5.43	NC
Total Kjeldahl Nitrogen (TKN)	mg/L	184	167 - 204	52.1	36.8 - 74.6	72
Total Suspended Solids (TSS)	mg/L	668	275 - 853	ND(4.00)	ND(4.00)	> 99

(a) Sample results may not be representative of the Island influent to Hamworthy treatment system (see Section 3.2).
NC - Percent removal not calculated because the effluent concentration was greater than the influent concentration, or the pollutant was not detected in the influent sample.
ND - Not detected (number in parentheses is detection limit).
< - Average result reported includes at least one non-detect value (calculation uses detection limits for non-detect results).
> - Indicates a minimum level of removal.

Table 4-4. Comparison of 2004 and 2005 Wastewater Treatment System Data for Holland America Veendam, Norwegian Star, Island Princess, and Holland America Oosterdam

Concentration and performance data for the wastewater treatment systems for the four vessels. Range and average analyte concentrations were determined from the weekly results presented in Tables 4-1 and 4-2, the influent to and effluent from treatment sampling points, respectively. Percent removals were calculated using the average influent and effluent analyte concentrations. Standard deviation of the average analyte concentrations calculated for the five weekly samples are denoted by "±".

Analyte	Unit	Average Influent to Treatment Concentration						Average Effluent from Treatment Concentration						Percent Removal	
		2004			2005			2004			2005			2004	2005
Holland America Veendam - Zenon Treatment System															
Ammonia As Nitrogen (NH3-N)	mg/L	71.0	±	10.5	56.0	±	12.6	18.4	±	9.24	7.58	±	6.57	74	86
Chemical Oxygen Demand (COD)	mg/L	1,480	±	520	1,130	±	475	37.0	±	3.62	50.4	±	9.96	97	96
Nitrate/Nitrite (NO3-N + NO2-N)	mg/L	<0.0560	±	0.00894	<0.776	±	0.431	<0.0760	±	0.0358	ND(0.260)	±	0.134	NC	> 67
Total Kjeldahl Nitrogen (TKN)	mg/L	105	±	21.6	79.2	±	14.2	25.3	±	8.09	<8.81	±	5.88	76	> 89
Total Suspended Solids (TSS)	mg/L	655	±	122	282	±	86.5	ND(5.00)	±	0	ND(4.20)	±	0.447	>99	> 98
Norwegian Star - Scanship Treatment System															
Ammonia As Nitrogen (NH3-N)	mg/L	ND(0.0500)	±	0	46.4	±	24.0	ND(0.0500)	±	0	32.3	±	5.14	NC	30
Chemical Oxygen Demand (COD)	mg/L	514	±	286	909	±	334	33.5	±	7.25	39.2	±	4.49	93	96
Nitrate/Nitrite (NO3-N + NO2-N)	mg/L	0.0578	±	0.0204	ND (0.400)	±	0.141	<0.173	±	0.177	<0.456	±	0.518	NC	NC
Total Kjeldahl Nitrogen (TKN)	mg/L	18.9	±	36.3	62.0	±	25.7	11.6	±	19.8	31.4	±	4.57	38	49
Total Suspended Solids (TSS)	mg/L	411	±	100.9	267	±	188	<5.30	±	0.45	<7.32	±	6.83	99	> 97
Island Princess - Hamworthy Treatment System															
Ammonia As Nitrogen (NH3-N)	mg/L	94.2	±	27.0	221	±	180 (a)	39.4	±	7.24	33.6	±	11.1	58	85
Chemical Oxygen Demand (COD)	mg/L	956	±	496	1,930	±	1,520 (a)	64.4	±	6.73	114	±	56.8	93	94
Nitrate/Nitrite (NO3-N + NO2-N)	mg/L	<0.0620	±	0.0217	ND(0.800)	±	0.274 (a)	<0.0860	±	0.0805	<5.21	±	4.68	NC	NC
Total Kjeldahl Nitrogen (TKN)	mg/L	181	±	102	270	±	226 (a)	43.2	±	9.45	34.6	±	12.3	76	87
Total Suspended Solids (TSS)	mg/L	1,150	±	335	933	±	812 (a)	<7.70	±	6.04	ND(4.00)	±	0	99	> 99

(a) Sample results may not be representative of the Island influent to Hamworthy treatment system (see Section 3.2).
NC - Percent removal not calculated because the effluent concentration was greater than the influent concentration, or the pollutant was not detected in the influent sample.
ND - Not detected (number in parentheses is detection limit).
< - Average result reported includes at least one non-detect value (calculation uses detection limits for non-detect results).
> - Indicates a minimum level of removal.
± -Standard deviation from the five weeks of samples.

Table 4-4 (Continued)

Holland America Oosterdam - ROCHEM Graywater Treatment System														
Ammonia As Nitrogen (NH3-N)	mg/L	ND(0.0500)	±	0	4.54	±	1.56	<0.058	±	0.0179	1.92	±	1.28	NC	58
Chemical Oxygen Demand (COD)	mg/L	405	±	78.9	254	±	50.1	62.3	±	11.3	<45.0	±	34.9	85	> 82
Nitrate/Nitrite (NO3-N + NO2-N)	mg/L	0.0360	±	0.0470	ND (0.260)	±	0.134	<0.0202	±	0.00931	ND(0.200)	±	0.134	44	NC
Total Kjeldahl Nitrogen (TKN)	mg/L	9.08	±	5.45	9.66	±	1.91	2.15	±	2.91	3.09	±	1.52	76	68
Total Suspended Solids (TSS)	mg/L	89.2	±	10.2	35.7	±	9.81	ND(5.00)	±	0	ND(4.00)	±	0	>94	> 89
Holland America Oosterdam - ROCHEM Sewage/Graywater Treatment System														
Ammonia As Nitrogen (NH3-N)	mg/L	ND(0.0500)	±	0	105	±	46.3	<0.569	±	1.07	49.7	±	14.0	NC	53
Chemical Oxygen Demand (COD)	mg/L	2,220	±	425	2,110	±	191	119	±	18.1	83.2	±	13.4	95	96
Nitrate/Nitrite (NO3-N + NO2-N)	mg/L	0.0268	±	0.146	<0.666	±	0.204	0.0559	±	0.0321	<1.69	±	2.11	NC	NC
Total Kjeldahl Nitrogen (TKN)	mg/L	193	±	6.84	184	±	18.0	58.4	±	31.2	52.1	±	14.9	70	72
Total Suspended Solids (TSS)	mg/L	727	±	219	668	±	243	ND(5.00)	±	0	ND(4.00)	±	0	>99	> 99

(a) Sample results may not be representative of the Island influent to Hamworthy treatment system (see Section 3.2).
NC - Percent removal not calculated because the effluent concentration was greater than the influent concentration, or the pollutant was not detected in the influent sample.
ND - Not detected (number in parentheses is detection limit).
< - Average result reported includes at least one non-detect value (calculation uses detection limits for non-detect results).
> - Indicates a minimum level of removal.
± -Standard deviation from the five weeks of samples.

5.0 DATA QUALITY

Quality assurance/quality control (QA/QC) procedures applicable to the 2005 sampling program are outlined in the *Addendum to the Quality Assurance Project Plan for Rulemaking Support for Large Cruise Ships in Alaska Waters (QAPP),* which is included in the Cruise Ship Rulemaking Record and is available upon request. This section describes the quality control practices used to assess the precision and accuracy of the analytical data presented in Section 4.0. Quality control (QC) practices used for this sampling program include the analysis of matrix spikes, duplicate samples, and quality control standard checks.

5.1 Analytical Quality Control

EPA verified that laboratory performance was acceptable by conducting quality control checks of the analytical data as specified by the QAPP. A data review chemist prepared a written data review narrative (Appendix B) describing any qualifications of the analytical data. All of the data were determined to be of acceptable quality.

5.2 Field Quality Control

Bottle blanks, field duplicate, and performance evaluation (PE) sample results are discussed in this subsection. Section 3.8 of the 2005 Sampling SAP discusses field QC specifications.

5.2.1 Bottle Blanks

Blanks were prepared for the various sample containers and bottles used for this program in order to monitor any contamination from the sample containers. Specifically, two bottle blanks were prepared for the 1-liter sample containers and one bottle blank was prepared for the 1-gallon container. Bottle blanks were prepared by filling the containers with deionized water, storing the containers for 24-hours, and then analyzing the water for nitrogen compounds.

Table 5-1 presents the analytical results of the bottle blanks. No nitrogen compounds were detected, indicating that there was no contamination from the sample containers.

5.2.2 Field Duplicates

Field duplicate samples were collected to assess the precision of the sample handling, preparation, and analysis process. The relative percent difference (RPD) between the two duplicate sample results is calculated and compared to the data quality objective. For this program, the QAPP provides an RPD target for field duplicate samples as less than 30% for all analytes of a specific analytical method.

Field duplicate samples were collected from the same source, at the same time, then stored and analyzed independently. The duplicate samples were collected as split samples poured from the same mixed composite sample container to minimize sample wastestream variability. A total of 6 duplicate samples were collected—one of each treated effluent sampling point (SP-2, SP-4, SP-6, SP-8, SP-10, and SP-11).

Table 5-2 presents analytical results and the RPDs for these duplicate samples. There was excellent precision in sampling and analysis for this sampling program. Of the 30 duplicate pairs listed in Table 5-2, 29 either achieved the RPD target, or the RPD could not be calculated because both of the duplicate samples were less than the reporting limit. The RPD could not be calculated for one of the duplicate pairs (Veendam TKN) because the analyte was detected at a level close to the detection limit in one sample but below the detection limit in the other. Analytical variability increases as analyte concentrations approach their detection limits.

In tables presenting the analytical results in Section 4.0, duplicate sample results are presented as averages (calculation uses detection limits for nondetected results).

5.2.3 Performance Evaluation Samples

Performance evaluation (PE) samples were procured from an independent, third party laboratory to assess the performance of the analytical laboratory. The PE samples were synthetic matrices similar in appearance and analytical performance as wastewater samples and were spiked with target analytes at known concentrations. The PE samples were packaged in containers identical to those used to collect wastewater samples and were then submitted to the laboratory along with the other wastewater samples using a similar sample identification number. In this way, the PE samples were "double-blind" as the laboratory was unaware of the receipt of the PE samples and had no knowledge of the target analyte concentrations. EPA measured the laboratory's analytical performance by comparing the PE sample analysis results against the certified known concentrations. The PE sample results were within guidelines for acceptable analytical results provided by the PE sample vendor, indicating excellent laboratory precision and accuracy. This assessment is documented in the memorandum *Performance Evaluation (PE) Samples for Evaluating Laboratory Analysis Performance*, dated November 14, 2005, which can be found in the Cruise Ship Rulemaking Record.

Table 5-1. Bottle Blank Analytical Results, Holland America Veendam

Analytical results for analytes detected in the bottle blanks. Three bottle blanks were collected during the sampling episode. All were analyzed as nondetect and shown as averages in this table.

Analyte	Unit	Bottle Blank-1 (SP-12)	Bottle Blank-2 (SP-12)	Bottle Blank-3 (SP-12)
Ammonia as Nitrogen	mg/L	ND(0.05)	ND(0.05)	ND(0.05)
Chemical Oxygen Demand	mg/L	ND(20.00)	ND(20.00)	ND(20.00)
Total Kjeldahl Nitrogen	mg/L	ND(1.00)	ND(1.00)	ND(1.00)
Total Suspended Solids	mg/L	ND(4.00)	ND(4.00)	ND(4.00)
Nitrate/Nitrite	mg/L	ND(0.05)	ND(0.05)	ND(0.05)

ND - Not detected (number in parentheses is detection limit).

Table 5-2. Field Duplicate Analytical Results for Holland America Veendam, Norwegian Star, Island Princess, and Holland America Oosterdam

Field duplicate analytical results for split samples collected from the same source, at the same time, stored and analyzed independently. See Table 2-1 and Figures 2-1 through 2-5 for the sampling point locations. Also listed are the average result and relative percent difference calculated for each duplicate pair.

Analyte	Unit	Original Effluent from Treatment	Duplicate Effluent from Treatment	Average	Relative Percent Difference
Holland America Veendam - SCC Numbers 66195 & 66196 (SP-2) (a)					
Ammonia As Nitrogen (NH3-N)	mg/L	0.0880	0.110	0.0990	22
Chemical Oxygen Demand (COD)	mg/L	37.0	35.0	36.0	5.6
Nitrate/Nitrite (NO3-N + NO2-N)	mg/L	ND (0.200)	ND (0.200)	ND (0.200)	NC
Total Kjeldahl Nitrogen (TKN)	mg/L	1.05	ND (1.00)	< 1.03	NC
Total Suspended Solids (TSS)	mg/L	ND (4.00)	ND (4.00)	ND (4.00)	NC
Norwegian Star - SCC Numbers 66341 & 66342 (SP-4) (a)					
Ammonia As Nitrogen (NH3-N)	mg/L	32.0	31.0	31.5	3.2
Chemical Oxygen Demand (COD)	mg/L	39.0	31.0	35.0	23
Nitrate/Nitrite (NO3-N + NO2-N)	mg/L	1.38	1.38	1.38	0.0
Total Kjeldahl Nitrogen (TKN)	mg/L	27.3	27.4	27.4	0.37
Total Suspended Solids (TSS)	mg/L	ND (4.00)	ND (4.00)	ND (4.00)	NC
Island Princess - SCC Numbers 66496 & 66497 (SP-6) (a)					
Ammonia As Nitrogen (NH3-N)	mg/L	47.0	47.0	47.0	0.0
Chemical Oxygen Demand (COD)	mg/L	221	207	214	6.5
Nitrate/Nitrite (NO3-N + NO2-N)	mg/L	ND (0.500)	ND (0.500)	ND (0.500)	NC
Total Kjeldahl Nitrogen (TKN)	mg/L	55.0	50.8	52.9	7.9
Total Suspended Solids (TSS)	mg/L	ND (4.00)	ND (4.00)	ND (4.00)	NC
Holland America Oosterdam - SCC Numbers 66642 & 66643 (SP-8) (a)					
Ammonia As Nitrogen (NH3-N)	mg/L	1.80	1.80	1.80	0.0
Chemical Oxygen Demand (COD)	mg/L	41.0	37.0	39.0	10
Nitrate/Nitrite (NO3-N + NO2-N)	mg/L	ND (0.200)	ND (0.200)	ND (0.200)	NC
Total Kjeldahl Nitrogen (TKN)	mg/L	2.85	3.76	3.31	28
Total Suspended Solids (TSS)	mg/L	ND (4.00)	ND (4.00)	ND (4.00)	NC

(a) Sampling point location; Figure 2-1 through 2-5.
NC - Percent removal not calculated because the effluent concentration was greater than the influent concentration, or the pollutant was not detected in the influent sample.
ND - Not detected (number in parentheses is detection limit).
< - Average result reported includes at least one non-detect value (calculation uses detection limits for non-detect results).

Table 5-2 (Continued)

Analyte	Unit	Original Effluent from Treatment	Duplicate Effluent from Treatment	Average	Relative Percent Difference
Holland America Oosterdam - SCC Numbers 66654 & 66655 (SP-10) (a)					
Ammonia As Nitrogen (NH3-N)	mg/L	50.0	53.0	51.5	5.8
Chemical Oxygen Demand (COD)	mg/L	76.0	84.0	80.0	10
Nitrate/Nitrite (NO3-N + NO2-N)	mg/L	5.42	5.44	5.43	0.37
Total Kjeldahl Nitrogen (TKN)	mg/L	52.0	52.0	52.0	0.0
Total Suspended Solids (TSS)	mg/L	ND (4.00)	ND (4.00)	ND (4.00)	NC
Holland America Oosterdam - SCC Numbers 66661 & 66662 (SP-11) (a)					
Ammonia As Nitrogen (NH3-N)	mg/L	17.0	15.0	16.0	13
Chemical Oxygen Demand (COD)	mg/L	68.0	71.0	69.5	4.3
Nitrate/Nitrite (NO3-N + NO2-N)	mg/L	ND (0.500)	ND (0.500)	ND (0.500)	NC
Total Kjeldahl Nitrogen (TKN)	mg/L	16.2	15.7	16.0	3.1
Total Suspended Solids (TSS)	mg/L	ND (4.00)	ND (4.00)	ND (4.00)	NC

(a) Sampling point location; Figure 2-1 through 2-5.
NC - Percent removal not calculated because the effluent concentration was greater than the influent concentration, or the pollutant was not detected in the influent sample.
ND - Not detected (number in parentheses is detection limit).
< - Average result reported includes at least one non-detect value (calculation uses detection limits for non-detect results).