Assessment of Cruise Ship and Ferry Wastewater Impacts in Alaska

Alaska Department of Environmental Conservation

Commercial Passenger Vessel Environmental Compliance Program

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Executive Summary

Cruise ships by their sheer size and passenger number are a highly visible industry in Alaska. Concerns about cruise ship pollution led to the creation of the Alaska Cruise Ship Initiative (ACSI) in 2000. Wastewater samples taken as part of the ACSI in 2000 indicated that the blackwater[1] treatment systems were not working properly and that graywater[2] quality was similar to blackwater. This information led to state and federal laws that now regulate cruise ship and ferry blackwater and graywater discharge in Alaska.

Before the passage of the state cruise ship law, blackwater and graywater from large cruise ships did not meet Alaska Water Quality Standards for ammonia, free chlorine, fecal coliform, copper, and zinc at the end of pipe. These ships would have exceeded Alaska Water Quality Standards for free chlorine, fecal coliform, and dissolved copper if they discharged while stationary. However, Alaska Water Quality Standards, except fecal coliform, were probably met in the receiving water while ships discharged underway due to substantial dilution.

Since the passage of the state law in 2001 and federal cruise ship law in 2000, most large cruise ships discharging into Alaska waters[3] have installed advanced wastewater treatment systems. The effluent quality produced by the advanced systems has dramatically improved from waste water discharged from most ships in 2000-2002. Therefore, ADEC considered the 2003 data to assess the impact of large cruise ship effluent in receiving waters. In 2003, these systems produced wastewater that met Alaska Water Quality Standards for most tested pollutants at the end of pipe. After applying a conservative dilution factor, Alaska Water Quality Standards were met in receiving water for all tested pollutants. Whole Effluent Toxicity (WET) testing conducted during 2003 in conjunction with dilution estimates indicates that effluent from ships with advanced wastewater treatment systems does not pose a risk to aquatic organisms, even during stationary discharge. No tested pollutant is present in concentrations that cause risks to human health.

Small cruise ships and Alaska Marine Highway System (AMHS) ferries use traditional treatment, not advanced systems to treat their blackwater. The quality of small ship effluent has remained relatively consistent from 2001 to 2003. Therefore, ADEC used all the data available to assess the impact of small vessel effluent on receiving waters. The wastewater produced by small vessels frequently exceeds eight (ammonia, free chlorine, fecal coliform, arsenic, copper, nickel, selenium, and zinc) Alaska Water Quality Standards at the end of pipe. After applying a conservative dilution factor, four (free chlorine, fecal coliform, copper, and zinc) Alaska Water Quality Standards may be exceeded in receiving water during stationary discharge. The discharge met Alaska Water Quality Standards for all tested pollutants in the receiving water during underway discharge due to the large dilution factor. In addition, WET testing conducted on six small vessels in conjunction with the sampling results indicates that small ship stationary effluent does pose some risk to the marine environment. Due to the high concentration of fecal coliform, the effluent from some small ships may pose a risk to human health in areas where aquatic life is harvested for raw consumption.

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[1] Black water is sewage.
[2] Graywater originates from showers, galley, laundry, etc.
[3] Alaska water is defined as 3 nautical miles from shore and the waters of the Alexander Archipelago defined in AS 46.03.490(18).

The wastewater samples taken from large and small vessels to date indicate that hazardous chemicals are not being discharged through these wastewater systems.

ADEC recommends that small vessels remain in the commercial passenger vessel program. Small vessels were granted three years to come into compliance with the cruise ship wastewater effluent standards. Further, in 2004, these vessels may submit an interim protection plan that, if approved by ADEC, extends the time for compliance with the effluent standards. This plan must detail the steps that the owner is taking to comply with the wastewater discharge limits including a description of the practices used to limit the adverse impacts of their discharges. Violations and fines could be levied against ships that are found violating the terms of their approved plan.

1. INTRODUCTION

1.1. Assessment Report

The 2001 state cruise ship legislation directed the Alaska Department of Environmental Conservation (ADEC) to submit a report to the Governor assessing commercial passenger vessels' discharges in Alaska marine waters. Using information from the 2000 – 2003 cruise ship seasons and other sources, this report satisfies the requirements to:

1. Characterize, to the extent possible, the risks to the marine and human environments posed by the discharge of sewage and graywater from commercial passenger vessels;

2. Evaluate the sewage and graywater treatment systems and technologies on the vessels, including an evaluation of whether small commercial passenger vessels should be made subject to the discharge limitations in AS 46.03.463; and

3. Recommend further action by the state in relation to the matters discussed in the report.

This report also presents general background information and detailed appendices of wastewater sampling data, in response to the numerous requests received by ADEC staff from industry, environmental groups, and other government agencies. Bilge and ballast water issues are a maritime wide concern and are beyond the scope of the 2001 legislation and this report.

1.2. Cruise Ship Industry Trends in Alaska

The first steamships began carrying tourists to Alaska in 1884,[4] making tourism one of Alaska's oldest industries. The number of cruise ship passengers that visit Alaska has increased by almost three and a half times since 1990. In 1990, 235,000 passengers traveled to Southeast Alaska. By 2003, the number of cruise ship passengers in Southeast Alaska increased to roughly 800,000[5] with tens of thousands of crew (Figure 1). By comparison, the state's population is approximately 650,000.[6] Roughly 95% of the current cruise ship traffic is concentrated in Southeast Alaska, a region with a population of approximately 73,000 people.[7] This makes the cruise ship industry extremely visible in the region. For example, Skagway - with a summer population of 1,200 people – often has more than 12,000 people visiting in a day. The other 5% of cruise ship traffic is directed primarily toward Southcentral Alaska, but a few small cruise ships visit Western Alaska.

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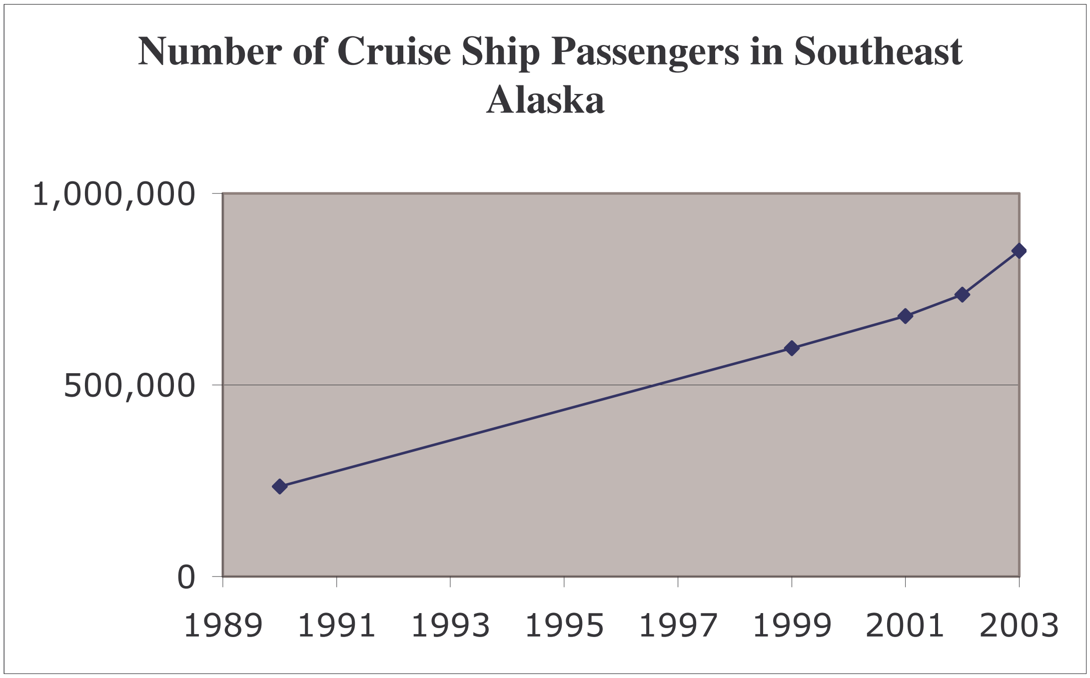
[4] Alaska Permanent Fund Corporation Alaska History Page http://www.apfc.org/library/AKHistoryD.cfm?s=5
[5] ADEC 2003 registration information
[6] Alaska Department of Labor and Workforce Development, Workforce Info Home Page http://almis.labor.state.ak.us/?PAGEID=67&SUBID=115
[7] Alaska Department of Labor and Workforce Development, Borough & Census Area Estimates 2000 – 2003, http://146.63.75.50/research/pop/estimates/02T2-1.xls

Figure 1. Cruise Ship Passenger Increase in Southeast Alaska



Source: Southeast Conference Report and ADEC Registration Statistics

The three most popular large cruise ship ports are Juneau, Ketchikan, and Skagway. Large ships tend to stop at the main Southeast Alaska ports and a large tidewater glacier (Glacier Bay or Hubbard). Some large cruise lines have trips that start in Southcentral Alaska (Seward) travel through southeast Alaska and end in Vancouver. The next voyage is reversed.

Alaska Marine Highway System (AMHS) ferries travel between Southeastern Alaska communities including Ketchikan, Juneau, and Skagway. These calls generally only last an hour or two. Small cruise lines explore remote bays and channels. They call on smaller Alaska ports and Native villages as well as the larger ports for most of a day. The small ships may venture from Alaska ports across the Bering Sea to the Russian Far East. The most popular ports for small ships are Sitka, Bartlett Cove, Skagway, Ketchikan, and Juneau.

Table 1 shows the number of cruise ship visits per port per year in 2003.[8] There are often multiple ships in a port in a single day.

[8] These numbers are derived from the 2003 Cruise Line Agencies of Alaska ship schedule. The actual visits may have varied slightly.

Table 1. Cruise Ship Visits Per Port in 2003

Place Name	Description	Number of small ship visits per year	Number of large ship visits per year
Adak	Port in Aleutian Islands	1	0
Anchorage	Port in Southcentral Alaska	8	0
Attu	Port in the Aleutian Islands	5	
Baranof Warm Springs	Port in Southeast Alaska	1	0
Bartlett Cove	Port inside Glacier Bay National Park	122	0
Cold Bay	Remote site	1	0
College Fiord	Tidewater Glacier in South central Alaska	7	147
Cordova	Port in Southcentral Alaska	16	0
Dutch Harbor	Unalaska Island (one of the Fox Is.) in the Aleutian Is.	7	3
Elfin Cove	Port in Southeast Alaska	25	0
Glacier Bay	Tidewater Glaciers, National Park in SE AK	See Bartlett Cove	207
Haines	Port in Southeast Alaska (Northern Lynn Canal)	67	13
Homer	Port in Southcentral (western Kenai Peninsula)	10	2
Hubbard Glacier	Tidewater Glacier near Yakutat on Gulf of Alaska	0	151
Icy Bay	Tidewater Glacier near Yakutat on Gulf of Alaska	0	2
Juneau	Port in Southeast Alaska	96	448
Ketchikan	Port in Southeast Alaska	100	408
Kodiak	Port in Kodiak Island (South central Alaska)	4	3
Misty Fiords	National Monument near Ketchikan	50	33
Nome	Western Alaska	2	3
Petersburg	Port in Southeast Alaska	96	0
Seward	Port in South Kenai Peninsula	0	98
Sitka	Port in Southeast Alaska (outside coast)	140	140
Skagway	Port in Southeast Alaska (Northern Lynn Canal)	100	328

Place Name	Description	Number of small ship visits per year	Number of large ship visits per year
St. Matthew	Island in the Bering Sea	9	0
St. Paul	Island in the Bering Sea	9	0
Tracy Arm	Tidewater Glacier in Southeast Alaska (between Juneau& Wrangell)	100	128
Valdez	Port in South central Alaska	16	0
Whittier	Port in South central Alaska	32	0
Wrangell	Port in Southeast Alaska	32	8

1.3. Concern about Cruise Ship Industry Environmental Practices

Tourism shares the rich marine environment with commercial fisheries, one of Alaska's largest private employers. Over 50% of America's seafood (5.1 billion of 9.4 billion pounds) is harvested from Alaska's waters.[9] The commercial fishing industry depends on the perception and actuality that Alaskan fish come from uncontaminated waters.

Alaska's Native peoples subsist off the bounty of the sea, relying heavily upon marine resources for nutrition, sustenance, cultural integrity, and spiritual well being. Alaska Natives were alarmed over potential cruise ship pollution and the fouling of especially vulnerable food items such as filter feeding mollusks.

In July 1999, Royal Caribbean Cruise Lines (RCCL) entered a federal criminal plea agreement involving total penalties of $6,500,000 for 1994 and 1995 environmental violations in Alaska including knowingly discharging oil and hazardous substances (dry-cleaning and photo processing chemicals) and making false entries in federally required Oil Record Books. RCCL admitted to a "fleet-wide practice of discharging oil contaminated bilge waste" and to submitting false statements in numerous jurisdictions. The $6,500,000 for Alaska violations was part of a larger $18,000,000 total federal plea agreement. In January 2000, RCCL entered into a state civil settlement for the Alaska violations. The state settlement required RCCL expenditures of over $3,325,000. This illegal discharge outraged many Alaskans, who began to question whether cruise ships met Alaska Water Quality Standards enforced by the Alaska Department of Environmental Conservation (ADEC).

Because of its international nature, the cruise industry was excluded from many of the U.S. environmental laws and regulations that land-based industries are required to meet. EPA did not issue a permit under the federal Clean Water Act for cruise ship wastewater discharges because of a marine vessels exemption that dates from the 1970s. The U.S. Coast Guard certifies marine sanitation devices (MSDs) for American flagged ships and checks to ensure that all applicable vessels have certified MSDs during ship inspections. They did not, however, monitor the wastewater effluent quality.

Large cruise ships operate under MARPOL (International Convention for the Prevention of Pollution from Ships), an environmental treaty drafted by the International Maritime

[9] "Fisheries of the United States 2002." September 2003. National Marine Fisheries Service, NOAA, U.S. Dept. of Commerce.

Organization (IMO), an agency of the United Nations. Annex IV of MARPOL addresses the disposal of sewage. Since the United States did not sign Annex IV, it is not mandatory, that ships follow Annex IV in the United States.[10]

1.4. Alaska Cruise Ship Initiative (ACSI)

In December 1999, ADEC responded to public concern and convened a forum to review and discuss the cruise industry's waste management and disposal practices in Alaska. The participants included the U.S. Coast Guard, the U.S. Environmental Protection Agency (EPA), Southeast Alaska communities, industry, Tribes, environmental groups, and concerned Alaskans. This effort became known as the Alaska Cruise Ship Initiative (ACSI). Goals of the ACSI included:

(1) identifying cruise ship waste streams,

(2) developing pollution prevention and waste management solutions,

(3) assessing and verifying compliance of volunteer wastewater sampling, and

(4) keeping the Alaskan public informed.

Voluntary sampling of large cruise ships in 2000 indicated that the marine sanitation devices (MSD) on most ships did not function well. U.S. Coast Guard regulations require that effluent from the type II MSD treatment systems installed on cruise ships contain no more than 200 fecal coliforms per 100 ml and 150 mg/l total suspended solids at installation.[11] Surprisingly, the fecal coliform results were as high as 16 million[12] in blackwater and 32 million in graywater.[13]

1.5. Alaska Specific Legislation

As a result of the ACSI efforts, the U.S. Congress enacted Title XIV – Certain Alaskan Cruise Ship Operations on December 21, 2000.[14] The law creates wastewater standards for vessels with 500 or more overnight passengers, and prohibits cruise ships from discharging raw sewage in areas that are more than 3 nautical miles from shore but still within the Inside Passage. These "donut holes" are now closed to discharge. (See Figure 2.) The regulations to implement the law became effective in July 2001[15] and are enforced by the U.S. Coast Guard.

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[10] EPA MARPOL 73/78 overview http://www.epa.gov/OWOW/OCPD/marpol.html

[11] 33 CFR Part 159 – Marine Sanitation Devices http://www.uscg.mil/d14/units/msohono/references/cfrs/sub%20o/part%20159.htm

[12] The geometric mean of fecal coliform samples was 12,824 for blackwater and 1,163,188 for graywater. See Appendix B. Large Ship Sampling Data Tables 47B & 51.

[13] Blackwater originates in toilets. Graywater comes from showers, sinks, kitchens, and laundry.

[14] "Title XIV—Certain Alaskan Cruise Ship Operations" of the Miscellaneous Appropriations Bill (H.R. 5666) on December 21, 2000 in the Consolidated Appropriations Act of 2001 (P.L. 106-554).

[15] 33 CFR Part 159 Subpart E – Discharge of Effluents in Certain Alaskan Waters by Cruise Vessel Operations.

Figure 2. Donut Holes Closed by Federal Cruise Ship Legislation

Under the federal legislation, large cruise ships may discharge blackwater and graywater in Alaska while underway.[16] During an underway discharge, blackwater effluent must contain no more than 200 fecal coliforms per 100 ml and no more than 150 mg/l total suspended solids. There are currently no federal effluent standards for underway graywater discharges.[17] Ships that discharge blackwater in Alaska while underway must take at least two blackwater samples per cruise ship season. The federal law allows continuous discharge of blackwater and graywater that meet more stringent standards (Table 2). A ship approved by the U.S. Coast Guard to discharge continuously must sample their wastewater twice per month

State of Alaska cruise ship legislation, AS 46.03.460 – AS 46.03.490,[18] was passed during a 2001 special session of the Alaska Legislature and became effective on July 1, 2001. The legislation establishes the Commercial Passenger Vessel Environmental Compliance (CPVEC) program in the ADEC. The regulations to implement the program, 18 AAC 69, were effective November 15, 2002.[19]

The state law sets standards and sampling requirements for the underway discharge of blackwater in Alaska that are identical to the blackwater standards in the federal law (Table 2). Because of the high fecal coliform counts detected in graywater during 2000, the state law also set graywater standards (Table 2). It also has provisions regarding the disclosure of solid waste and hazardous waste disposal information.

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[16] Traveling at least 6 knots while at least 1 nautical mile from shore.

[17] The Administrator of the EPA may promulgate different wastewater effluent standards in the future. EPA recently began the process of evaluating whether the current federal standards are consistent with Alaska Water Quality Standards.

[18] Available at: http://old-www.legis.state.ak.us/cgi-bin/folioisa.dll/stattx01/query=as+46!2E03!2E460/doc/{@17677}?

[19] Regulations were drafted by stakeholder committee and brought through formal rule making process. They are available at http://www.state.ak.us/dec/title18/wpfiles/69mas.doc

The CPVEC program applies to both large and small commercial passenger vessels. A small commercial passenger vessel provides overnight accommodations for 50 to 249 passengers. State law defines a large commercial passenger vessel as one that provides overnight accommodations for 250 or more passengers.[20] Several key aspects of the CPVEC program, such as payment of environmental compliance fees and compliance with wastewater discharge standards, did not apply to small commercial passenger vessels until January 1, 2004.[21] These vessels did, however, have to adhere to the wastewater sampling, record keeping, and reporting requirements as soon as the law was effective.

Table 2. Comparison of State and Federal Laws

Law	State	Federal
# Overnight Passengers	50+	500+
Discharge Limits	At Least 1 mile from shore @ min. 6 knots	
	BW & GW	BW only
Fecal Coliform/100 ml	Geometric Mean of 200	200
Total Suspended Solids (mg/l)	150	150
Discharge Limits	Continuous Discharge (at anchor)	
	BW & GW	BW & GW
Fecal Coliform/100 ml	Refers to Fed Law	Geometric Mean of 20
Chlorine (mg/l)		10
Total Suspended Solids (mg/l)		30

1.6. Science Advisory Panel

During the ACSI, a Science Advisory Panel was organized to independently address the scientific questions surrounding the impact of cruise ship waste in Alaska. The Science Advisory Panel is a group of scientists and engineers whose work and conclusions are not subject to government or industry approval. The nine core members of the Panel include an oceanography professor, NOAA physical oceanographer, ADEC environmental engineer, civil engineering professor, oceanographer for a law firm, microbiologist, NOAA senior staff scientist, chemistry professor, and an EPA senior toxicologist. While Panel members were not compensated, a paid facilitator, who is a retired U.S. Coast Guard Captain-of-the-Port and industrial toxicologist, supported the Panel's work.

[20] AS 46.03.490

[21] Small ship owners/operators may obtain an extension of time for compliance with AS 46.03.463(a) - (d) by submitting an approved plan for interim protective measures. See 18 AAC 69.045 for details.

The North West Cruiseship Association funded the facilitator and travel expenses for non-governmental panel members in 2000 - 2001. ADEC funded the facilitator and travel expenses for non-governmental panel members in 2002. The efforts of the Science Advisory Panel culminated in the publication of *The Impact of Cruise Ship Wastewater Discharge on Alaska Waters*[22] in November 2002 and several other papers available on the following website: http://www.state.ak.us/dec/press/cruise/documents/sciencepanel.htm Science Advisory Panel work is referenced throughout this report.

[22] http://www.state.ak.us/dec/press/cruise/documents/impactcruise.htm

2. WASTEWATER SAMPLING DESIGN, RATIONALE, and STATISTICS

2.1. Data Reliability and Representative Nature

It is crucial that wastewater sample data is reliable[23] and representative.[24] This data is used to determine compliance with the cruise ship laws and to conduct scientific analysis. Large vessels that discharge in Alaska take at least two compliance samples per cruise ship season to satisfy both state and federal cruise ship laws. ADEC, U.S. Coast Guard, and the Northwest Cruiseship Association have established a Quality Assurance/Quality Control (QAQC) plan that ensures that the sample results are reliable.[25]

The QAQC plan includes standard sampling and laboratory quality control elements with additional instructions tailored to a maritime facility. It lists all the pollutants to be tested and the EPA analytical methods to be used. The QAQC requirements include duplicate sampling, sampling audits, and a lab technical systems audit. The U.S. Coast Guard cruise ship regulations require third party sampling. ADEC regulations are consistent with other state wastewater programs and allow industry to collect samples using their own staff. However, large cruise ships sample to satisfy the requirements of both the federal and state law. Therefore, a third party sampler takes all required large vessel wastewater samples. Small ship operators are not bound by the federal law but have also chosen to use third party samplers.

ADEC also performs independent compliance sampling and analysis. ADEC tests for pollutants listed in the QAQC plan as well as other pollutants of concern.

Because each ship is configured differently and follows unique wastewater management practices, the state also requires the owner/operator to submit a vessel specific sampling plan (VSSP). The VSSP plan, approved by ADEC before sampling begins, must demonstrate that the sample will be representative of the wastewater discharged from the particular ship.

From 2001 through 2002, wastewater sampling on large cruise ships was dictated by the ability to discharge underway and to get the samples to the laboratory within the EPA mandated six hour holding time for fecal coliform analysis. This frequently meant that wastewater samples were taken in the middle of the night when the volume of wastewater was low. The ideal wastewater sample would have been taken during daytime when the volume of wastewater production was high. These samples did not sample the treatment abilities at normal flow conditions and therefore are not representative. By 2003, only large cruise ships with advanced wastewater treatment systems discharged wastewater in Alaska. These vessels were approved for continuous discharge and were sampled during the day in port while the vessel was discharging into receiving water. These continuous discharge samples should be representative of the wastewater effluent produced by the wastewater treatment systems and discharged into receiving water.

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[23] Reliability reflects the degree of certainty.

[24] The objective of representative sampling is to ensure a sample or group of samples accurately characterizes site conditions. ASTM Method 6044-96 Standard Guide for Representative Sampling for Management of Wastes and Contaminated Media. http://www.astm.org/cgi-bin/SoftCart.exe/DATABASE.CART/PAGES/D6044.htm?L+mystore+nhpu4885

[25] The most current version, "Northwest CruiseShip Association, Discharge of Effluents in Certain Alaska Waters by Cruise Vessel Operations, 2003 Operating Season Quality Assurance/Quality Control Plan For Sampling and Analysis of Treated Sewage and Graywater From Commercial Passenger Vessels," is available at: http://www.state.ak.us/dec/press/cruise/pdf/03qaqc.pdf

Small cruise ships are sampled in port because of the economic hardship it would cause if third party samplers traveled with the vessels. The time spent in Juneau, where small cruise ships do their wastewater sampling, is often used to disembark passengers and to get ready for the next cruise. There is usually little to no wastewater produced during this day. State cruise ship regulations[26] effective November 2002 gave small ships the ability to have their crew sample their wastewater and submit it to a laboratory for analysis. This would enable underway sampling; however, none of the ships have exercised this option. Despite these issues, the data obtained over the last three seasons, when considered in its entirety, does provide a reasonable picture of the pollutants that are present in small cruise ship wastewater discharges.

Alaska Marine Highway System ferries were usually sampled in port; however, there were usually passengers still aboard the vessel. The wastewater samples from the ferries were therefore representative of the wastewater effluent produced by its wastewater treatment system.

2.2. Sampling Program Evolution from 2000 - 2003

The sampling strategy that guided the voluntary sampling program in 2000 differs from the regulatory program existing today. Table 3 and Table 4 highlight the evolution of the sampling program. The pollutants with asterisks are defined as conventional pollutants in 40 CFR Part 401.16 and are typically tested in the effluent of wastewater treatment plants. On the advice of the Science Advisory Panel, ADEC expanded this sampling list. This group is referred to as conventional pollutants throughout this report. Priority pollutants refer to an EPA list of 126 specific pollutants that include heavy metals and specific organic chemicals.

Table 3. Conventional Pollutants

Pollutant	2000	2001	2002	2003
Ammonia	√	√	√	√
pH*	√	√	√	√
Biochemical Oxygen Demand (BOD)*	√	√	√	√
Chemical Oxygen Demand (COD)	√	√	√	√
Total Suspended Solids (TSS)*	√	√	√	√
Total and Free Chlorine	√	√	√	√
Fecal Coliform*	√	√	√	√
Settleable Solids		√	√	√
Oil and Grease*		√	√	√
Total Organic Carbon (TOC)		√	√	√
Conductivity		√	√	√

[26] 18 AAC 69, http://www.state.ak.us/dec/title18/wpfiles/69mas.pdf

Pollutant	2000	2001	2002	2003
Alkalinity		√	√	√
Total Nitrogen[27]		√	√	√
Total Phosphorus		√	√	√

Table 4. Priority Pollutants

Pollutant	2000	2001	2002	2003
Base, Neutral, Acids (BNAs)	√	√	√	√
Pesticides[28]	√			
Polychlorinated Biphenyls (PCBs)	√	√	√	
Volatile Organic Chemicals (VOC)	√	√	√	√
Trace Metals	√	√	√	√
Cyanide	√			

2000 Season's Voluntary Program

The voluntary ACSI program in 2000 applied to large ships only. The goals of the 2000 sampling program were to characterize wastewater quality and to determine if hazardous substances were discharged to receiving water through the wastewater systems. The voluntary program included two samples per season.

2001 Season - Moving from Voluntary Sampling to Compliance Sampling

In 2001, the purpose of the sampling shifted to assess compliance with the laws as well as conducting scientific impact analyses. All ships discharging in Alaska water are required by Alaska statute[29] to sample twice a year. On the advice of the Science Advisory Panel, ADEC increased conventional pollutants monitoring requirements. The pesticides and their metabolites on the 2000 priority pollutant list[30] have not been used in the U.S. for many years and were not detected in any of the 2000 samples. The U.S. Coast Guard and ADEC therefore removed pesticides from the priority pollutant list in 2001.

2002 Season

The sampling strategy for the majority of the large ships was the same as in 2001. However, six of seven large ships, with advanced wastewater treatment systems, had U.S. Coast Guard

[27] Total nitrogen includes ammonia, nitrate, nitrite, and total kjeldahl nitrogen (TKN).
[28] aldrin, chlordane, dieldrin, 4,4'-DDT, 4,4'-DDE, 4,4'-DDD, alpha endosulfan, beta endosulfan, endosulfan sulfate, endrin, endrin aldehyde, heptachlor, heptachlor epoxide, alpha BHC, beta BHC, gamma BHC, delta BHC and toxaphene
[29] AS 46.03.465(d)

[30]

approval for continuous discharge and were sampled in port.[31] Small ships took their first priority pollutant samples in 2002 and began sampling for the expanded list of conventional pollutants.

2003 Season

In 2003, the wastewater data from large ships reflected the continued increase in the number of large vessels with advanced treatment technology, from seven of 25 (28%) in 2002 to eighteen[32] of 32 (56%) in 2003. Small vessels continued to discharge and be sampled in port.

As in previous years, one of the two sampling events included testing for priority pollutants. ADEC and U.S. Coast Guard dropped PCBs from the priority pollutant sampling list for 2003 season because of the 2000 - 2002 history of non-detects. The priority pollutants (Base/Neutrals & Acids, Volatile Organic Chemicals, and Trace Metals) analyzed in 2003 are listed in Appendix A.

At the recommendation of the Science Panel, ADEC also tested vessel wastewater for commonly used organophosphorus pesticides at the end of 2003 season. No pesticides were detected. ADEC will continue to test for organophosphorus during the 2004 cruise ship season.

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[31] The following ships had advanced wastewater treatment systems that were approved for continuous discharge by the U.S. Coast Guard: Celebrity *Mercury* and Holland America *Ryndam, Statendam, Volendam, Veendam*, and *Zaandam*. The Radisson *Seven Seas Mariner* had an advanced system, but it was not approved for continuous discharge.

[32] Princess - *Star Princess, Sun Princes, Dawn Princess, Coral Princess, Pacific Princess, Island Princess*
Celebrity - *Mercury*
Holland America – *Ryndam, Statendam, Maasdam, Volendam, Veendam, Zaandam*
Carnival – Carnival *Spiri*t (graywater only)
Norwegian – *Norwegian Sun, Norwegian Sky, Norwegian Wind*
Radisson - *Seven Seas Mariner*

3. APPLYING ALASKA WATER QUALITY STANDARDS TO RECEIVING WATER

The State of Alaska has Water Quality Standards adopted in regulation. These standards help protect human health and the environment. ADEC tested for pollutants in samples taken at the discharge point inside the vessel. These effluent samples are also referred to as "end of pipe" samples. Discharges from the ship mix with the receiving water. ADEC, therefore, applied modeled dilution factors to the vessels' end of pipe sample results to determine whether Water Quality Standards were met in receiving waters.

In this document, ADEC refers to the Water Quality Standards located in *ALASKA WATER QUALITY CRITERIA MANUAL FOR TOXIC AND OTHER DELETERIOUS ORGANIC AND INORGANIC SUBSTANCES* amended through May 15, 2003, TABLE IV. AQUATIC LIFE CRITERIA FOR MARINE WATERS.[33] ADEC took a conservative approach and applied the more stringent chronic rather than acute water quality standards.

[33] This document is available at http://www.state.ak.us/dec/dawq/wqs/documents/70wqsmanual.doc

4. WASTEWATER CHARACTERISTICS – LARGE SHIPS

4.1. Statistics

Since 2000, ADEC has collected substantial amounts of wastewater sampling data on cruise ships and ferries subject to the Commercial Passenger Vessel Environmental Compliance Program. In order to characterize the central tendency of the large quantity of data, the median was used. The median is the middle of a distribution: half the scores are above the median and half are below the median. The median is less sensitive to extreme scores than an average and is thus a better measure for skewed distributions. Medians are used to present all pollutant data in this report except for fecal coliform. Much of the fecal coliform data was highly skewed so a geometric mean was used to summarize this data.

Geometric Mean

When distributions are more highly skewed, a geometric mean is used. A geometric mean moderates the effect of a single high value. A geometric mean is computed as follows:

$(X_1 X_2 .. X_n)^{1/n} =$

Example:

$(1 \times 2 \times 10 \times 10{,}000)^{1/4} = 21$

4.2. Summary of Conventional Pollutant Data

2000 Sampling Data

Table 5 compares the median and geometric mean values of conventional pollutants tested in 2000 wastewater samples. Appendix B Large Ship Sampling Data presents the detailed sampling results from individual ships. Table 5 and subsequent tables also present the applicable Alaska Water Quality Standards[34] for comparison.

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[34] ADEC, Alaska Water Quality Criteria Manual For Toxic and other Deleterious Organic & Inorganic Substances May 15, 2003, Table IV located at: http://www.state.ak.us/local/akpages/ENV.CONSERV/dawq/wqs/documents/70wqsmanual.doc. Fecal coliform standards and pH standards from ADEC Water Quality Standards, 18 AAC 70, http://www.state.ak.us/dec/title18/wpfiles/70mas.pdf. The most conservative standard is listed.

Table 5. 2000 Large Ship Conventional Pollutant Data

The values for all pollutants, except fecal coliforms, are medians. Fecal coliform information is represented as a geometric mean.

Water Type (# samples) Large Ship Appendix B Table #	Collected from	Fecal Coliform (MPN/100 ml)	TSS mg/l	BOD mg/l	COD mg/l	Ammonia mg/l	pH	Total Cl mg/l	Free Cl mg/l
	AK WQS	14	n/a	n/a	n/a	17.00[35]	6.5-8.5	0.0075*	0.0075*
	MDL	2	1.3	2	3.0	0.03	0.1	0.10	0.10
GW - Accommodations. & Laundry (3) Table 51.	CT	6	138.7	61	240.0	25.12	6.8	0.37	0.26
GW – Accommodations (3) Table 52.	CT	104	455.0	355	1,340.0	24.94	8.4	0.78	ND
GW - Laundry (10) Table 53.	CT	8	39.0	86	300.0	0.39	9.2	0.28	ND
GW – Galley (11) Table 54.	CT	13,750	223.5	850	940.0	2.19	6.9	ND	ND
Mixed GW (24) Table 55.	CT	118,052	92.0	170	405.0	1.40	6.8	ND	ND
Mixed GW (13) Table 56.	DB	1,163,188	250.0	450	940	0.20	5.95	ND	ND
BW&GW (11) Table 60.	DB	12,824	110.0	130	395.0	8.50	7.0	ND	ND
BW (22) Table 61.	MSD	18,213	407.0	130	1,210.0	100.00	7.6	0.33	ND

MPN = Most Probable Number MDL = Method Detection Limit GW = Graywater BW = Blackwater
CT= Collecting Tank DB =Double Bottom Tank
MSD = Marine Sanitation Device ND= Non Detect
*Note that the MDL for chlorine is higher than the chronic water quality standard.

The graywater sampled from accommodations & laundry, accommodations only, and laundry only had low fecal coliform counts. Galley graywater and mixed graywater had very high levels of fecal coliforms. Graywater sampled from double bottom tanks had higher fecal coliform results than the corresponding wastewater type sampled from collecting tanks. This is illustrated in Table 7.

[35] The ammonia Water Quality Standard is for unionized ammonia. All samples were analyzed for total ammonia. Salinity, temperature, and pH affect the unionized portion of total ammonia. ADEC used TABLE IX. TOTAL AMMONIA CHRONIC CRITERIA FOR SALTWATER AQUATIC LIFE to calculate the total ammonia that corresponds to the unionized ammonia Water Quality Standard. Southeast Alaska port conditions were used for this calculation: 10 psu salinity; pH of 7.0; and temperature of 12.5 degrees Celsius. Using these ambient conditions, the total ammonia equivalency to the unionized Water Quality Standard is 17 mg/L.

The treated blackwater results included two samples that had been treated with a reverse osmosis treatment system before being stored in the double bottom tank. These samples had results below the limit of detection for fecal coliforms, which lowered the geometric mean substantially. Even with the addition of these two samples, the treated blackwater had a high geometric mean of fecal coliform, 18,213 MPN/100ml, as well as a high median of ammonia, 100.0 mg/l, and COD, 1,210.0 mg/l. These results indicate that the blackwater treatment systems were not functioning properly.

2001 Sampling Data

The state cruise ship law was effective in the summer of 2001. From this year forward, blackwater samples were taken primarily to ensure compliance with effluent standards. (When blackwater and graywater are mixed, it is considered blackwater.) Graywater was phased into the state program. Any graywater discharged in the state needed to be sampled as of 2001 but was not subject to the effluent standards until 2003. This is the cause of the disparity between the graywater effluent samples and the blackwater effluent samples presented in Table 6.

The low fecal coliform and TSS level of the mixed black and graywater occurred because 12 of the 16 samples were taken from advanced wastewater treatment systems on the Celebrity *Mercury* and Holland America *Statendam*. No fecal coliforms or TSS were detected in the effluent from those systems. The other ship that sampled its mixed black and graywater discharged outside Alaska water and was sampled voluntarily.

Table 6. 2001 Large Ship Conventional Pollutant Data

The values for all pollutants, except fecal coliforms, are medians. Fecal coliform information is represented as a geometric mean.

Water Type (# samples) Large Ship Appendix B Table #	Collected from	Fecal Coliform (MPN/ 100 ml)	TSS mg/l	BOD mg/l	COD mg/l	Ammonia mg/L	pH	Total Cl mg/L	Free Cl mg/l
	AK WQS	14	n/a	n/a	n/a	17.00	6.5-8.5	0.0075*	0.0075*
	MDL	2	1.3	2	3.0	0.03	0.1	0.10	0.10
GW – Accommodations (15) Table 32.	DB	10,896	66.0	217	460.0	0.11	6.8	ND	ND
GW – Accommodations (15) Table 33.	CT	2,189	55.5	170	300.0	0.99	7.6	3.00	0.30
GW - Galley (10) Table 34.	DB	784,072	383.0	1,300	1,707.0	0.65	4.4	ND	ND
GW – Galley (23) Table 35.	CT	402**	266.0	740	1,410.0	1.00	7.0	4.00	1.30
Mixed GW (4) Table 36.	DB	649,994	151.3	194	289.0	0.32	6.5	ND	ND
Mixed GW (13) Table 37.	CT	38,933	76.5	220	520.0	0.48	7.2	ND	ND
GW - Laundry (7) Table 38.	DB	651,460	43.0	160	410.0	0.40	8.3	0.20	ND
GW - Laundry (2) Table 39.	CT	30	22.0	100	650.0	Not taken	8.4	1.03	1.03
Mixed BW&GW (16) Table 46.	MSD	2	0.7	3	11.5	0.63	7.1	ND	ND

*Note that the MDL for chlorine is higher than the chronic water quality standard.

** Some samples did not meet the fecal coliform 6 hour holding time and were not analyzed.

Water Type (# samples) Large Ship Appendix B Table #	Alkalinity mg/l	Conductivity (Umhos/cm	Oil &Grease mg/l	Phosphorous Total mg/l	Nitrate as N mg/l	TOC mg/l	Total Kjeldahl Nitrogen mg/l	Settleable Solids mg/l
AK WQS								
MDL	0.5	1	1.5	0.01	1.0	1.0	1.0	0.1
GW (15) Table 40.	59.6	883	47.0	5.54	0.0	305.0	12.0	0.2
BW (5) Table 47.	125.4	3,590	0.2	9.05	0.6	100.0	27.8	4.5

MPN = Most Probable Number   MDL = Method Detection Limit   GW = Graywater   BW = Blackwater
CT= Collecting Tank   DB =Double Bottom Tank
MSD = Marine Sanitation Device   ND= Non Detect

Table 7 compares 2000 and 2001 samples of wastewater that were held for up to 20 hours in double bottom (DB) tanks with wastewater collected and discharged immediately from collecting tanks (CT). The concentration of fecal coliform, TSS, and BOD increased when wastewater was stored in the double bottom tanks indicating a degradation of the effluent quality.

Table 7. Comparison of 2000 and 2001 Large Ship Wastewater Samples Held in Double Bottom vs. Collecting Tanks

# Samples	Sample Date	Sample From	Waste Type	Fecal[36]	TSS	BOD	COD	Ammonia	pH	Total Cl	Free Cl
			Units	MPN/100ml	mg/l	mg/l	mg/l	mg/l			mg/l
			AK WQS	14	n/a	n/a	n/a	17.00	6.5-8.5	0.0075	0.0075
			MDL	2	1.3	2	3.0	0.03	0.1	0.10	0.10
13	2000	DB	Mixed Graywater	1,163,188	250.0	450	940	0.20	5.95	ND	ND
15	2001	DB	GW accommodation	10,896	66.0	217	460.0	0.11	6.8	ND	ND
10	2001	DB	GW Galley	784,072	383.0	1,300	1,707.0	0.65	4.4	ND	ND
4	2001	DB	Mixed GW	649,994	151.3	194	289.0	0.32	6.5	ND	ND
7	2001	DB	GW laundry	651,460	43.0	160	410.0	0.40	8.3	0.20	ND
11	2000	DB	BW&GW	12,824	110.0	130	395.0	8.50	7.0	ND	ND
3	2000	CT	GW Accommodation and Laundry	6	138.7	61	240.0	25.12	6.8	0.37	0.26
3	2000	CT	GW accommodation	104	455.0	355	1,340.00	24.94	8.4	0.78	ND
10	2000	CT	GW laundry	8	39.0	86	300.0	0.39	9.2	0.28	ND
11	2000	CT	GW galley	13,750	223.5	850	940.0	2.19	6.9	ND	ND
24	2000	CT	Mixed GW	118,052	92.0	170	405.0	1.40	6.8	ND	ND
15	2001	CT	GW Accommodation	2,189	55.5	170	300.0	0.99	7.6	3.00	0.30
23	2001	CT	GW Galley	402	266.0	740	1,410.0	1.00	7.0	4.00	1.30
13	2001	CT	Mixed GW	38,933	76.5	220	520.0	0.48	7.2	ND	ND
2	2001	CT	GW laundry	30	22.0	100	650.0	Not taken	8.4	1.03	1.03
			Median DB	**194,343**	**130.7**	**206**	**435.0**	**0.36**	**6.7**	**ND**	**ND**
			Median CT	**587**	**92.0**	**170**	**520.0**	**1.20**	**7.2**	**.37**	**ND**

<u>2002 Sampling Data</u>

In 2002, the graywater from large ships was still exempt from the fecal coliform and total suspended solids standards. The graywater effluent quality that year was still quite poor. The median and geometric mean values of both the 2002 graywater and blackwater are presented in Table 8.

[36] This value is geometric mean not median.

Table 8. 2002 Large Ship Conventional Pollutant Data

The values for all pollutants, except fecal coliforms, are medians. Fecal coliform information is represented as a geometric mean.

Water Type (# samples) Large Ship Appendix B Table #	Collected from	Fecal Coliform (MPN/100 ml)	TSS mg/l	BOD mg/l	COD mg/l	Ammonia mg/L	pH	Total Cl mg/l	Free Cl mg/l
	AK WQS	14	n/a	n/a	n/a	17.00	6.5-8.5	0.0075*	0.0075*
	MDL	2	1.3	2	3.0	0.03	0.1	0.10	0.10
GW - Galley (7) Table 21.	DB or CT	6,279	1,320.0	2,790	5,110.0	2.66	4.11	ND	ND
GW - Accom & Laundry (12) Table 23.	DB or CT	47,357	130.5	367	615.0	1.07	6.72	ND	ND
Mixed GW (19) Table 25.	CT or DB	38,603	190.0	328	621.0	1.00	6.14	ND	ND
BW (21) Table 15.	Various	5	0.1	3	61.6	18.80	7.5	ND	ND

Water Type (# samples) Large Ship Appendix B Table #	Collected From	Alkalinity mg/l	Conductivity (Umhos/cm	Oil &Grease mg/l	Phosphorous Total mg/l	Nitrate as N mg/l	TKN mg/L	TOC mg/l	Settleable Solids mg/l
	AK WQS								
	MDL	0.5	1	1.5	0.01	1.0	1.0	1.0	0.1
GW - Galley (7) Table 22.	DB or CT	0.25	1,810	520.0	14.10	0.2	0.2	1,600.0	44.0
Accom. & Laundry (12) Table 24.	DB or CT	73.5	5,090	140.0	5.50	0.2	0.2	209.5	0.1
Mixed GW (19) Table 26.	CT or DB	53.4	1,920	95.0	3.99	0.2	0.2	162.5	0.5
BW (21) Table 15.	DB, CT, or MSD	135.0	685	0.9	3.21	0.1	0.1	23.0	0.1

MPN = Most Probable Number   MDL = Method Detection Limit   GW = Graywater   BW = Blackwater
CT= Collecting Tank   DB =Double Bottom Tank
MSD = Marine Sanitation Device   ND= Non Detect
*Note that the MDL for chlorine is higher than the chronic water quality standard.

Galley graywater showed lower levels of fecal coliform bacteria than the accommodations or mixed graywater but the levels of BOD, COD, and TSS are much higher. Galley graywater is a more complex wastewater to treat than laundry or domestic wastewater because of the high amount of oil, grease, and solids.

The conventional pollutant results for blackwater were much lower than the graywater results with the exception of a high ammonia median of 18.80 mg/l. The seven ships that discharged blackwater in Alaska had advanced wastewater treatment systems,[37] which resulted in a low fecal coliform geometric mean of 5 MPN/100ml and median TSS of 0.1 mg/L.

<u>2003 Sampling Data</u>

In 2003, large cruise ship graywater and blackwater were subject to the fecal coliform and total suspended solids standards. The median and geometric mean values of pollutants detected in graywater and blackwater are presented in Table 9.

[37] The following ships had advanced wastewater treatment systems that were approved for continuous discharge by the U.S. Coast Guard: Celebrity *Mercury* and Holland America *Ryndam, Statendam, Volendam, Veendam*, and *Zaandam*. The Radisson *Seven Seas Mariner* had an advanced system, but it was not approved for continuous discharge.

Table 9. 2003 Large Ship Conventional Pollutant Data

The values for all pollutants, except fecal coliforms, are medians. Fecal coliform information is represented as a geometric mean.

Water Type (# samples) Large Ship Appendix B Table #	Fecal Coliform (MPN/100 ml)	TSS mg/l	BOD mg/l	COD mg/l	Ammonia mg/l	pH	Total Cl mg/l	Free Cl mg/l
AK WQS	14	n/a	n/a	n/a	17.00	6.5-8.5	0.0075*	0.0075*
MDL	2	1.3	2	3.0	0.03	0.1	0.10	0.10
Graywater (3) Table 3.	7	0.0	23	67.0	1.30	7.3	ND	ND
Blackwater (57) Table 1.	1	0.0	4	72.0	25.10	7.4	ND	ND

Water Type (# samples) Large Ship Appendix B Table #	Alkalinity mg/l	Conductivity (Umhos/cm	Oil &Grease mg/l	Phosphorous Total mg/l	Nitrate as N mg/l	TOC mg/l	Total Kjeldahl Nitrogen mg/l	Settleable Solids mg/l
AK WQS								
MDL	0.5	1	1.5	0.01	1.0	1.0	1.0	0.1
Graywater (3) Table 4.	34.1	199	6.2	0.23	0.0	12.7	4.8	0.0
Blackwater (57) Table 2.	219.5	987	0.0	3.60	0.0	19.4	29.0	0.0

MPN = Most Probable Number MDL = Method Detection Limit GW = Graywater BW = Blackwater

CT= Collecting Tank DB =Double Bottom Tank

MSD = Marine Sanitation Device ND= Non Detect

*Note that the MDL for chlorine is higher than the chronic water quality standard.

Only one ship, the Carnival *Spirit,* discharged graywater in Alaska. The graywater from this ship was treated through a reverse osmosis advanced wastewater treatment system. This was the cause of the dramatic improvement in the 2003 graywater quality. It should be noted, however, that the COD level was still high.

In 2003, the number of ships with advanced wastewater treatment systems increased to 18.[38] These ships discharged their wastewater in Alaska. Most of these ships mixed their graywater

[38] Princess - *Star Princess, Sun Princes, Dawn Princess, Coral Princess, Pacific Princess, Island Princess*
Celebrity - *Mercury*
Holland America – *Ryndam, Statendam, Maasdam, Volendam, Veendam, Zaandam*
Carnival – Carnival *Spirit* (graywater only)
Norwegian – *Norwegian Sun, Norwegian Sky, Norwegian Wind*
Radisson - *Seven Seas Mariner*

and blackwater together resulting in blackwater. The blackwater effluent was of high quality but still had elevated levels of ammonia and COD.

4.3. Pollutants in Effluent that Exceed Alaska Water Quality Standards

The medians of most pollutants in effluent were below Alaska Water Quality Standards. Table 10 draws upon Table 5 – 9 for conventional pollutants and Appendix C. Summary of Large Ship Sampling for Priority Pollutants to highlight the medians that do not meet Alaska Water Quality Standards at the end of pipe. A shaded cell indicates that the concentration in effluent was below the standard.

Table 10. End of Pipe - Large Ship Pollutant Medians that Do Not Meet Alaska Water Quality Standards

			Blackwater				Graywater			
Pollutant	**Units**	**AWQS**	**2003**	**2002**	**2001**	**2000**	**2003**	**2002**	**2001**	**2000**
Ammonia	mg/l	17.00	25.10	18.80		100.00				25.12
Free Chlorine	mg/l	0.0075							1.30	0.26
Fecal Coliform	MPN/100 ml	14.0				18,213		47,357	784,072	1,163,188
Copper, dissolved	ug/l	3.1	10.70	7.72	133.85	225.00		31.65	255	31.01
Nickel, dissolved	ug/l	8.2	12.60	16.70	20.50			12.70	15.0	
Zinc, dissolved	ug/l	81.0	109.5	195.5	169.5	425.0		262.0	270.0	

Note: Fecal coliform information is a geometric mean.

4.4. Pollutants that Exceed Alaska Water Quality Standards in Receiving Water

The Science Advisory Panel concluded in their November 2002 *The Impact of Cruise Ship Wastewater Discharge on Alaska Waters* report that even the wastewater discharged in 2000 from vessels moving at a minimum of 6 knots, 1 mile from shore, met Alaska Water Quality Standards in the receiving water.[39] For large ships, this is due to a minimum underway dilution factor of 50,000.[40]

ADEC therefore focused on the impact that cruise ship wastewater effluent has on the receiving waters during stationary discharge. ADEC modeled the dilution of large cruise ship effluent during stationary discharge during a very conservative scenario, a neap tide[41] in Skagway, using the EPA approved Visual Plumes model and information provided by operators in their Vessel Specific Sampling Plans. ADEC calculated a dilution factor for each ship's discharge. (More detailed information on the model used to calculate the dilution factor is included in Appendix D. Cruise Ship Stationary Discharge Modeling.) The lowest dilution factor calculated by the model was 8 for blackwater and 5 for graywater. The concentration of a pollutant in Table 10 was divided by these factors to arrive at the pollutant concentration that is expected in the receiving waters (Table 11). If the pollutant concentration met the Alaska Water Quality Standards in receiving water after applying the dilution factor, the cell is shaded.

Table 11. Modeled Large Ship Median Pollutant Concentrations in Receiving Waters during Stationary Discharge (Fecal coliform information is a geometric mean.)

			Blackwater				Graywater			
Pollutant	Units	AWQS	2003	2002	2001	2000	2003	2002	2001	2000
Free Chlorine	mg/l	0.0075							0.26	0.052
Fecal Coliform	MPN/100 ml	14.0				2,276.63		9,471	156,814	232,638
Copper, dissolved	ug/l	3.1			16.73	28.13		6.33	51.0	6.2

Of the many (176) pollutants that were tested in effluent during 2003, none are expected to exceed Alaska Water Quality Standards in the receiving water during stationary discharge.

4.5. Whole Effluent Toxicity Testing

Whole Effluent Toxicity (WET) testing is an alternative to directly analyzing environmental samples for individual constituents. WET testing addresses the effect that simultaneous exposure to a mixture of pollutants has on an organism.

[39] Science Advisory Panel "The Impact of Cruise Ship Wastewater Discharge on Alaska Waters", November 2002 http://www.state.ak.us/dec/press/cruise/documents/impact/executivesummary.htm

[40] Large Cruise Ship Dilution factor = 4 x (ship width x ship draft x ship speed)/(volume discharge rate)4x (30 m x 8 m x 3.10 m sec-1)/(0.06 m3sec-1) ≈ 50,000

[41] A tide of minimum range occurring at the first and the third quarters of the moon.

There are two ways to perform the WET test: static non-renewal and static renewal. In a static non-renewal test, organisms are exposed to a single portion of the solution for the duration of the test. In a static renewal test, organisms are exposed to fresh changes of the test water every day. This testing method is more conservative because the organisms are exposed to the effluent at the same strength for a longer time period. ADEC conducted WET testing using the static renewal method on commercial passenger vessels in 2002[42] and again in 2003.[43]

<u>2002 Testing</u>

This test was designed to simulate exposure to the concentration of pollutants that could be found in the receiving waters behind a moving cruise ship. Because of the high dilution rates associated with moving cruise ships, the dilution series started at 50% effluent and increased by a factor of 10 such that the percent effluent progressively decreased. The concentrations tested were 50%, 5%, 0.5%, 0.05%, 0.005%, and 0.0005% effluent. The dilution series represented concentrations that are attained in receiving waters with dilution factors (df) of 2, 20, 200, 2,000, 20,000, and 200,000. A typical large cruise ship discharging 200 cubic meters per hour while traveling at 6 knots (11 km/hour) would have a dilution factor of about 50,000.[44]

WET results are presented in Table 12. The percentages represent the highest effluent concentration at which the tests exhibited no observable acute or chronic effects. Values in parentheses show dilution factors associated with the no observed effect concentrations (NOEC).

Table 12. Large Ship 2002 No Observed Effect Concentration (NOEC) and Dilution Factor (df)

Vessel	Treatment System	Mysid Acute NOEC	Topsmelt Acute NOEC	Bivalve Larvae NOEC	Echinoderm Fertilization NOEC
Dawn Princess Graywater	Chlorine added to collection tanks	5% (df=20)	5% (df=20)	0.5% (df=200)	0.5% (df=200)
Mercury Mixed Effluent	Reverse Osmosis	50% (df=2)	50% (df=2)	50% (df=2)	50% (df=2)
Volendam Mixed Effluent	Aerated Membrane (Ultrafiltration)	50% (df=2)	5% (df=20)	5% (df=20)	5% (df=20)

The *Dawn Princess* graywater demonstrated some effect at 50% concentration (one part sea water to one part wastewater) in the acute test and some effect at 5% wastewater concentration in the chronic tests. This limited toxicity occurred despite the fact that no residual chlorine was found in the sample. However, the ammonia concentration was 10 mg/L. Samples from the *Mercury* did not demonstrate any toxicity, even at a 1:2 dilution. The *Volendam* sample

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[42] Science Advisory Panel "Review and Comment Regarding Whole Effluent Toxicity Test Results for Five Commercial Passenger Vessels in Alaska July 2002" http://www.state.ak.us/dec/press/cruise/documents/wetfinal.htm and "Lab results for Whole Effluent Toxicity test (WET) – August 2002" http://www.state.ak.us/dec/press/cruise/documents/wetreport.htm

[43] ADEC "2003 Whole Effluent Toxicity Results for Commercial Passenger Vessels in Alaska" http://www.state.ak.us/dec/press/cruise/documents/wet/2003%20Whole%20Effluent%20Toxicity%20(WET)%20Test%20Discussion.pdf

[44] The Panel has developed a formula for predicting dilution/dispersion in the wake of large cruise ships.
Dilution factor = 4 x (ship width x ship draft x ship speed)/(volume discharge rate)

demonstrated an effect at 50% for the Topsmelt acute test and on both chronic test species but had no effect on the Mysid acute test with as little as a 1:2 dilution.

The observed WET values would not be of concern during underway discharge because dilution factors of greater than 1:200 would be easily achieved in the receiving water. During 2002, *Dawn Princess* discharged its graywater underway a minimum one nautical mile from shore going at least 6 knots. The vessel held its blackwater until it was outside Alaska waters. As of 2003, this vessel mixes its accommodations graywater with its blackwater and then treats it through an advanced wastewater treatment system that meets the stringent standards for continuous discharge. (See Table 2.) Wastewater from the *Mercury* and *Volendam* continue to be discharged in port. *Mercury* effluent is diluted by a factor of 18 and *Volendam* effluent is diluted by a factor of 60, even during stationary discharge during a neap tide. (See Appendix D. Cruise Ship Stationary Discharge Modeling Table 4.) Therefore, the effluent from these three ships is not expected to cause toxicity to marine organisms.

<u>2003 Testing</u>

From the period of June through September 2003, ADEC conducted WET testing on the following large vessels: *Norwegian Wind, Sun Princess, Carnival Spirit,* and *Ryndam*. These ships represented all four of the advanced treatment systems operated on cruise ships in Alaska. These large vessels had obtained U.S. Coast Guard certification to discharge wastewater any time anywhere, including in port.

ADEC designed the 2003 WET test to determine if there are any negative effects to the marine environment during stationary discharges when dilution factor will be low. Therefore, the dilution series only increased by a factor of 2 instead of 10. The dilution series was 50%, 25%, 12.5%, 6.25%, 3.125%, and 1.5% effluent. This series represented concentrations that are attained in receiving waters with dilution factors (df) of 2, 4, 8, 16, 32, and 66.7.

ADEC calculated the ship specific dilution factors during a worst case scenario, a stationary discharge during a neap tide in Skagway, using the Visual Plumes model.[45] (See Appendix D. Cruise Ship Stationary Discharge Modeling.) When the ship specific dilution factor calculated by the Visual Plumes model is greater than the No Observed Effect Concentration dilution factor (df), no toxicity is expected.

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[45] ADEC used the Visual Plumes mode UM3 with the Brooks far field solution. For more information on this model go to http://www.epa.gov/ceampubl/swater/vplume/

Table 13. Large Ship 2003 Whole Effluent Toxicity Test Results & Ship Specific Dilution Factor during Neap Tide

No Observed Effect Concentration (NOEC) and Dilution Factor (df)

Vessel	Treatment System	Ship Specific Dilution Factor from Visual Plumes model	Mysid Acute NOEC	Topsmelt Acute NOEC	Bivalve Larvae NOEC		Echinoderm Fertilization NOEC
					Normality[46]	Survival	
Norwegian Wind Mixed Effluent	Scanship Bioreactor/ultra-filtration	24	>50% (df=2)	12.5% (df=8)	6.25% (df=16)	50% (df=2)	25% (df=4)
Ryndam Mixed Effluent	Aerated Membrane (Ultrafiltration)	60	>50% (df=2)	50% (df=2)	12.5% (df=8)	50% (df=2)	50% (df=2)
Sun Princess Mixed Effluent	Hamworthy Bioreactor and Ultrafiltration	15	12.5% (df=8)	12.5% (df=8)	<1.5%[47] (unknown)	50% (df=2)	<1.5% (unknown)
Spirit Graywater	Reverse Osmosis	5	>50% (df=2)	50% (df=2)	25% (df=4)	50% (df=2)	Unable to run[48]

These results indicate that **large ships' wastewater effluent will not cause toxicity in receiving waters, even during periods of minimal tidal flux**.

4.6. Summary of Large Ship Data 2000 – 2003

Wastewater production volumes depend primarily on the number of passengers and crew on a vessel. The volumes are also affected by ship waste management practices and configuration. The average large cruise ship with 2,500 people (including crew) produces 800 cubic meters or 211,200 gallons of wastewater per day. Between 90-95% of that wastewater is graywater.

Before the passage of the state cruise ship law, blackwater and/or graywater from large cruise ship samples taken at the end of pipe did not meet Alaska Water Quality Standards for ammonia, free chlorine, fecal coliform, copper, and zinc (Table 10). Wastewater effluent is diluted by a small factor during stationary discharge. If large ships discharged while stationary, the Water Quality Standards would have been exceeded for free chlorine, fecal coliform, and copper in the receiving water. However due to substantial dilution, all Alaska Water Quality Standards, except fecal coliform, were met in the receiving water while ships discharged underway.

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[46] Normality measures the normal development of the bivalve larvae.
[47] S. propuratus gametes is not a bivalve but was substituted because the mussels and oysters would not spawn due to elevated summer temperatures.
[48] The organisms were not available when the sample arrived in September.

The state cruise ship law, effective in July 2001, allowed large cruise ships to seek interim protective measures that extended the time for compliance with the graywater standards until January 1, 2003.[49] All ships that discharged graywater in state water from 2000 through 2002 sought and were granted this extension. Under the interim protective measures, the ships could only discharge graywater while underway. In contrast, the blackwater discharged from large ships was subject to the state effluent standards in July 2001. This is the cause of the drastic difference in the effluent quality of the gray and blackwater until 2003 when the standards applied to both wastewater types.

In 2001, the data reflect that 21 of the 24 large ships stopped discharging blackwater into Alaska water. The fecal coliform levels in blackwater fall drastically because the two ships[50] that continued to discharge blackwater in Alaska waters had advanced wastewater treatment technology. The other ship[51] treated blackwater through a traditional macerator chlorination system. The graywater results, especially the galley water, continued to indicate poor effluent quality.

The 2000 and 2001 data also indicate that holding water in double bottom tanks for later discharge increases the concentration of fecal coliform, TSS, and BOD. It is possible that the double bottom tanks were contaminated with blackwater and that fecal coliform multiplied in the warm holding environment.

In 2002, the overall quality of the graywater was still poor. Seven ships[52] had advanced wastewater treatment systems and discharged blackwater in Alaska. The blackwater quality was dramatically better than the graywater but still had elevated levels of ammonia.

In 2003, the only large ships that discharged wastewater in Alaska had advanced wastewater treatment systems. Most of these systems treated blackwater but one system treated graywater. Most tested pollutants met Water Quality Standards at the end of pipe without dilution. Even considering the minimal dilution that occurs during stationary discharge during a neap tide, the concentration of tested pollutants met all Alaska Water Quality Standards in receiving water. (See Table 11.)

The quality of large cruise ship wastewater reflected the continued increase in the number of vessels that installed advanced treatment technology, from two of 24 (8%) in 2001 to seven of 25 (28%) in 2002 to eighteen[53] of 32 (56%) in 2003.

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[49] AS 46.03.463(c)
[50] Celebrity *Mercury* and Holland America *Statendam*
[51] Universe Explorer
[52] The following ships had advanced wastewater treatment systems that were approved for continuous discharge by the U.S. Coast Guard: Celebrity *Mercury* and Holland America Ryndam, Statendam, Volendam, Veendam, Zaandam. The Radisson *Seven Seas Mariner* had an advanced system, but it was not approved for continuous discharge.
[53] Princess - Star Princess, Sun Princes, Dawn Princess, Coral Princess, Pacific Princess, Island Princess
Celebrity - Mercury
Holland America – Ryndam, Statendam, Maasdam, Volendam, Veendam, Zaandam
Carnival – Carnival Spirit (graywater only)
Norwegian – Norwegian Sun, Norwegian Sky, Norwegian Wind
Radisson - Seven Seas Mariner

Risk Characterization

ADEC expects that only large cruise ships with advanced wastewater treatment systems will discharge wastewater in Alaska in the future. WET testing results and a comparison of sample results with Alaska Water Quality Standards indicate that the effluent from these advanced systems is not expected to cause toxicity to the marine environment. No human health risk is posed by the low concentration of tested pollutants found in wastewater samples.

The wastewater samples indicate that hazardous materials are not being discharged through these wastewater treatment systems.

5. WASTEWATER CHARACTERISTICS – SMALL SHIPS

5.1. Statistics

Since 2001, ADEC has collected substantial amounts of wastewater sampling data on cruise ships and ferries subject to the Commercial Passenger Vessel Environmental Compliance Program. In order to characterize the central tendency of the large quantity of data, the median was used. The median is the middle of a distribution: half the scores are above the median and half are below the median. The median is less sensitive to extreme scores than an average and is thus a better measure for skewed distributions. Medians are used to present all pollutant data in this report. Much of the fecal coliform data was highly skewed so a geometric mean was used to summarize this data.

Geometric Mean

When distributions are more highly skewed, a geometric mean is used. A geometric mean moderates the effect of a single high value. A geometric mean is computed as follows:

$(X_1X_2..X_n)^{1/n} =$

Example:

$(1 \text{ x } 2 \text{ x } 10 \text{ x } 10{,}000)^{1/4} = 21$

5.2. Summary of Conventional Pollutant Data

There were only three small ship wastewater samples taken in 2000, too few to analyze. Only a short list of conventional pollutants was sampled during 2001. In 2002 and 2003, small ship wastewater samples were analyzed for the expanded list of conventional pollutants as well as for priority pollutants.

Small vessel conventional pollutant data taken in 2001 through 2003 is summarized according to wastewater effluent type in Table 14. Detailed sampling results from individual ships can be found in Appendix E: Small Ship Sampling Data.

Table 14. Small Ship Conventional Pollutants

The values for all pollutants, except fecal coliform, are medians. Fecal coliform information is represented as a geometric mean.

	Number of Samples	Ammonia total (as N)	pH	BOD5	COD	TSS	Total Chlorine Residual	Fecal Coliform	Free Chlorine Residual
Year Wastewater Type Small Ship Appendix E Table #		**mg/l**		**mg/l**	**mg/l**	**mg/l**	**mg/l**	**MPN/100**	**Mg/l**
MDL		0.03	0.10	2	3.0	1.3	0.10	2	0.10
AK WQS		17.00	6.5 – 8.5	n/a	n/a	n/a	0.0075*	14	0.0075*
2001 GW Table 30	25	1.03	7.5	212	525.0	49.6	ND	103	ND
2002 GW Table 16	11	0.31	7.2	175	400.0	54.1	0.65	222[54]	ND
2003 GW Table 1	23	0.46	7.3	199	330.0	55.6	0.70	48	ND
2001 BW Table 32	16	3.30	7.8	60	863.0	115.8	0.03	10,561	ND
2002 BW Table 20	12	16.15	7.5	137	805.5	133.0	ND	11,582	ND
2003 BW Table 5	21	11.50	7.9	39	625.0	87.1	ND	500	ND
2001 BW&GW Mixed Table 31	10	7.72	7.3	130	814.0	108.0	1.00	3,720	0.10
2002 BW&GW Mixed (Table 18)	17	16.80	7.5	154	835.0	77.0	0.25	5,487	1.10[55]
2003 BW&GW Mixed Table 3	18	29.00	7.0	346	545.0	128.5	ND	56,513	ND

*Note that the MDL for chlorine is higher than the chronic water quality standard.

MPN = Most Probable Number MDL = Method Detection Limit GW = Graywater BW = Blackwater

ND= Non Detect

[54] Results skewed by one result of 16,000,000.

[55] In several instances only free chlorine was tested. This resulted in higher medians for free than total chlorine.

	Number of Samples	Conductivity	Oil & Grease	Total Organic carbon	Alkalinity	Total Nitrate and Nitrite as N	Total Phosphorus	Total Kjeldahl Nitrogen	Total Settleable Solids
		umhos/cm	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
MDL		1.0	1.5	1.0	0.5	1.0	0.01	1.0	0.1
WQS		n/a							
2002 GW (Table 17)	1	369	52.0	352.0	61.0	0.5	0.86	0.4	0.1
2003 GW (Table 2)	23	429	15.0	68.9	76.3	0.0	1.60	6.3	0.0
2002 BW (Table 21)	1	34,500	8.5	299.0	116.0	0.5	2.33	5.7	0.1
2003 BW (Table 6)	21	28,800	7.3	29.7	125.0	0.0	3.30	39.0	2.0
2002 BW&GW Mixed (Table 19)	4	29,750[56]	20.0	305.0	77.9	0.5	1.36	23.2	0.1
2003 BW&GW (Table 4)	18	17,900	62.0	158.5	204.5	0.0	3.50	35.0	2.4

MPN = Most Probable Number   MDL = Method Detection Limit   GW = Graywater   BW = Blackwater
ND= Non Detect

Fecal coliform was at its lowest level in graywater and blackwater during 2003.

In the mixed black and graywater, there is a substantial increase in the concentration of fecal coliform from 3,720 MPN/100 ml in 2001 to 56,513 MPN/100 ml in 2003.

5.3. Pollutants in Effluent that Exceed Alaska Water Quality Standards

The medians of most pollutants in effluent were below Alaska Water Quality Standards. Table 15 draws from Table 14 for conventional pollutants and Appendix F. Summary of Small Ship Sampling for Priority Pollutants to highlight the pollutant medians that do not meet Alaska Water Quality Standards at the end of pipe. A shaded cell indicates that the concentration in the effluent was below the standard.

[56] Eight samples were analyzed for conductivity.

Table 15. End of Pipe - Small Ship Pollutants Medians that Do Not Meet Alaska Water Quality Standards

			Graywater		Treated Blackwater		Treated Blackwater & Graywater Mixed	
Pollutant	Units	AWQS	2003	2002	2003	2002	2003	2002
Ammonia	mg/l	17.00					29.00	
Free Chlorine	mg/l	0.0075	ND	ND				1.10
Fecal Coliform	MPN/100 ml	14	48	222	500	11,582	56,513	5,487
Arsenic	ug/l	36.0			42.8	44.9		
Copper	ug/l	3.1	74.8	27.4	6.4	11.1	22.0	76.3
Nickel	ug/l	8.2			13.0	14.9	12.2	16.6
Selenium	ug/l	71.0			171.0	170.0	98.2	134.0
Zinc	ug/l	81.0	150.0	86.9			98.5	165.0

Note: Fecal coliform information is a geometric mean.

5.4. Pollutants that Exceed Alaska Water Quality Standards in Receiving Water

The Science Advisory Panel concluded in *The Impact of Cruise Ship Wastewater Discharge on Alaska Waters* report that the wastewater discharges from vessels moving at a minimum of 6 knots, 1 mile from shore, would meet Alaska Water Quality Standards in the receiving water.[57]

ADEC therefore focused on the impact that cruise ship wastewater effluent has on receiving waters during stationary discharge. ADEC modeled the dilution of small ship effluent during stationary discharge during a very conservative scenario, a neap tide[58] in Skagway, using the EPA approved Visual Plumes model and the information provided by operators in their Vessel Specific Sampling Plans. ADEC calculated a dilution factor for each ship's discharge. (More detailed information on the model used to calculate the dilution factor can be found in Appendix D Cruise Ship Stationary Discharge Modeling.) The lowest dilution factor calculated by the model was 1.5 for graywater, 38 for blackwater, and 8 for mixed wastewater. The concentration of a pollutant in Table 15 was divided by these factors to arrive at the pollutant concentration that is expected in the receiving waters (Table 16). If the predicted pollutant concentration met the Alaska Water Quality Standards in receiving water after applying the dilution factor, the cell is shaded.

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[57] Science Advisory Panel "The Impact of Cruise Ship Wastewater Discharge on Alaska Waters," November 2002 http://www.state.ak.us/dec/press/cruise/documents/impact/executivesummary.htm

[58] A tide of minimum range occurring at the first and the third quarters of the moon.

Table 16. Modeled Small Ship Median Pollutant Concentrations in Receiving Waters during Stationary Discharge

			Graywater		Treated Blackwater		Mixed Blackwater & Graywater	
Pollutant	**Units**	**AKWQS**	**2003**	**2002**	**2003**	**2002**	**2003**	**2002**
Free Chlorine	mg/l	.0075						0.14
Fecal Coliform	MPN/100 ml	14	32	148		305	7,064	686
Copper	ug/l	3.1	49.8	18.3				9.5
Zinc	ug/l	81.0	100.0					

Note: Fecal coliform information is a geometric mean

In 2003, of all the pollutants that were tested (176), only three pollutants are expected to regularly exceed Water Quality Standards during stationary discharge.

5.5. Whole Effluent Toxicity Testing

Whole Effluent Toxicity (WET) testing is an alternative to directly analyzing environmental samples for individual constituents. WET testing addresses the effect that simultaneous exposure to a mixture of pollutants has on an organism.

There are two ways to perform the WET test: static non-renewal and static renewal. In a static non-renewal test, test organisms are exposed to a single portion of the solution for the duration of the test. In a static renewal test, test organisms are exposed to fresh changes of water every day for the duration of the test. Static renewal testing is more conservative because the test organisms are exposed to the effluent at the same strength for a longer time period. ADEC conducted WET testing using the static renewal method on commercial passenger vessels in 2002[59] and again in 2003.[60]

2002

This test was designed to simulate exposure to the concentration of pollutants that would likely be found in the receiving waters behind a moving ship. Because of the high dilution rates associated with moving ships, the dilution series started at 50% effluent and increased by a factor of 10 such that the percent effluent tested progressively decreased. The concentrations tested were 50%, 5%, 0.5%, 0.05%, 0.005%, and 0.0005% effluent. The dilution series represented

[59] Science Advisory Panel "Review and Comment Regarding Whole Effluent Toxicity Test Results for Five Commercial Passenger Vessels in Alaska July 2002" http://www.state.ak.us/dec/press/cruise/documents/wetfinal.htm and "Lab results for Whole Effluent Toxicity test (WET) – August 2002" http://www.state.ak.us/dec/press/cruise/documents/wetreport.htm
[60] ADEC "2003 Whole Effluent Toxicity Results for Commercial Passenger Vessels in Alaska" http://www.state.ak.us/dec/press/cruise/documents/wet/2003%20Whole%20Effluent%20Toxicity%20(WET)%20Test%20Discussion.pdf

concentrations that are attained in receiving waters with dilution factors (df) of 2, 20, 200, 2,000, 20,000, and 200,000. For comparison, a small cruise ship with a width of 10 meters and a draft of 1 meter, discharging 0.4 cubic meters per hour (0.0001 cubic meters per second) while traveling at 6 knots (3.09 m/s) multiplied by the small ship factor of 3 would give a dilution factor of about 927,000.[61]

WET test results are presented in Table 17. The percentages represent the highest effluent concentration at which the tests exhibited no observable acute or chronic effects. Values in parentheses show dilution factors associated with the no observed effect concentrations (NOEC).

Table 17. Small Ship 2002 No Observed Effect Concentration (NOEC) and Dilution Factor (df)

Vessel	Treatment System	Mysid Acute NOEC	Topsmelt Acute NOEC	Bivalve Larvae NOEC	Echinoderm Fertilization NOEC
Kennicott Mixed Effluent	Macerator/ Chlorinator	5% (df=20)	5% (df=20)	5% (df=20)	0.5% (df=200)
Yorktown Clipper Blackwater	Macerator/ Chlorinator	50% (df=:2)	50% (df=2)	50% (df=2)	50% (df=2)
Yorktown Clipper Graywater	Chlorine injection	0.5% (df=200)	0.5% (df=200)	0.5% (df=200)	0.05% (df=2,000)

The WET tests indicated that acute or chronic toxic effects on marine organisms are not expected to occur in receiving water when vessels discharge underway. However, the *Kennicott* mixed effluent could cause chronic effects (echinoderm fertilization) during stationary discharge, even when considering the ship specific dilution factor of 23 calculated by the Visual Plumes model. The *Yorktown Clipper* blackwater effluent would not cause toxicity even during stationary discharge. The *Yorktown Clipper* graywater effluent could cause both chronic and acute toxicity during stationary discharge, even when ship specific dilution factor of 1.5 is applied. (See Appendix D. Cruise Ship Stationary Discharge Modeling Table 5 for ship specific dilution factors.) The chronic toxicity of the *Kennicott* mixed effluent and the *Yorktown Clipper* graywater may be explained by the excessive chlorination of the effluent. Alaska's Water Quality Standard for total residual chlorine is 7.5 ug/l. The total residual chlorine in the *Kennicott* mixed effluent and the *Yorktown Clipper* graywater was 30,300 ug/l and 16,200 ug/l respectively.

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[61] The Science Panel has developed a formula for predicting dilution/dispersion in the wake of small cruise ships.
Dilution factor = 3 x (ship width x ship draft x ship speed)/(volume discharge rate);
http://www.state.ak.us/dec/press/cruise/documents/impact/dilutionwastewater.htm
The dilution factor is large for small ships compared to large ships because of the much smaller volume discharge rate.

2003

ADEC designed the 2003 WET test to determine the likelihood of negative effects to the marine environment during stationary discharges when dilution factor will be low. Therefore, the dilution series only increased by a factor of 2 instead of 10. The dilution series was 50%, 25%, 12.5%, 6.25%, 3.125%, and 1.5% effluent. This series represented concentrations that are attained in receiving waters with dilution factors of 2, 4, 8, 16, 32, and 66.7.

ADEC calculated the dilution factors during a worst case scenario, a stationary discharge during a neap tide in Skagway, using the Visual Plumes model.[62] (See Appendix D. Cruise Ship Stationary Discharge Modeling.) When the ship specific dilution factor calculated by the Visual Plumes model is greater than the No Observed Effect Concentration dilution factor (df), no toxicity is expected.

Table 18. Small Ship 2003 Whole Effluent Toxicity Test Results & Dilution Factor during Neap Tide

No Observed Effect Concentration (NOEC) and Dilution Factor (df)

Vessel	Treatment System	Ship Specific Dilution Factor from Visual Plumes model	Mysid Acute NOEC	Topsmelt Acute NOEC	Bivalve Larvae NOEC		Echinoderm Fertilization NOEC
					Normality[63]	Survival	
Spirit of Oceanus Mixed Effluent	BW Biological GW untreated	8	25% (df=4)	12.5% (df=8)	<1.5% (unknown)	12.5% (df=8)	<1.5% (unknown)
Spirit of Columbia Blackwater	Macerator/ Chlorinator	50[64]	>50% (df=2)	50% (df=2)	50% (df=2)	50% (df=2)	25% (df=4)
Spirit of Columbia Graywater	Untreated	2.5[65]	12.5% (df=8)	25% (df=4)	6.25% (df=16)	25% (df=4)	<1.5% (unknown)

On the *Spirit of Oceanus,* the blackwater is treated with a biological system and the graywater is untreated. The effluent is mixed before it is discharged. The mixed effluent is only expected to receive a dilution factor of 8 in the receiving water during stationary discharge. We do not expect the mixed effluent would cause acute toxicity even at this small dilution factor. The tests show that the effluent exhibits some chronic toxicity (bivalve larvae normality and echinoderm

[62] ADEC used the Visual Plumes mode UM3 with the Brooks far field solution. For more information on this model go to http://www.epa.gov/ceampubl/swater/vplume/
[63] Normality is the normal development of the bivalve larvae.
[64] *Spirit of Columbia's* blackwater is discharged from a pump under the waterline, which increases dilution.
[65] *Spirit of Columbia's* graywater is discharged directly from drains by means of gravity, which decreases dilution.

fertilization) at this dilution rate. However, in practice this vessel only discharges while underway when the effluent is expected to be diluted by a factor of approximately 100,000.[66] Therefore no toxicity to marine organisms is expected to result under normal operating procedures.

The *Spirit of Columbia* blackwater should not cause acute or chronic effects to marine organisms in receiving waters, even during stationary discharge.

The *Spirit of Columbia* graywater may cause acute and chronic effects on marine organisms while discharging in port. There is little dilution of its graywater because it is discharged above waterline. Graywater from this vessel is not expected to cause toxicity in receiving water during underway discharge because of the high dilution factor experienced while underway.

5.6. Summary of Small Ship Data 2001 – 2003

The state defines small ships as vessels that carry between 50 and 249 overnight passengers for hire. The average small cruise ship with 100 people (including crew) produces 9.5 cubic meters or 2,500 gallons of waste water per day. Of that amount 830 gallons is seawater used for toilets. There is roughly 16.7 gallons of graywater used per person or 1,670 gallons total.[67]

Small cruise ships and Alaska Marine Highway System (AMHS) ferries treat their blackwater with marine sanitation device (MSD). Some mix their blackwater and graywater together and then treat the wastewater through a MSD. Some vessels treat their graywater with chlorine before discharge while others discharge untreated graywater.

In 2001, small ships were only sampled for a short list of conventional pollutants. In 2002 and 2003, small ships sampled for the expanded list of conventional pollutants as well as for priority pollutants. Graywater effluent usually met the fecal coliform and total suspended solids effluent standards established by the state law. Blackwater and mixed black and graywater usually met the total suspended solids standards but exceeded the fecal coliform standard.

Risk Characterization

The wastewater samples indicate that hazardous chemicals are not being discharged through these wastewater systems. However, small ship effluent may not meet Alaska Water Quality Standards for free chlorine, fecal coliform, copper, and zinc in receiving water during stationary discharge.

The 2003 WET results were less toxic than those of 2002. In both years, the level of toxicity did not present a concern during underway discharge but graywater would, in all likelihood, cause marine toxicity during stationary discharge.

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[66] Dilution calculation for small ships Dilution factor = 3 x (ship width x ship draft x ship speed)/(volume discharge rate) =3 x (_____m x _____m x _____m sec^{-1})/(_____$m^3 sec^{-1}$), the vessel's width is 15.3 m with a maximum draft of 4.15 m. ADEC assumed ship speed at 6 knots (3.09 m sec^{-1}) and the discharge rate of .0057 $m^3 sec^{-1}$
Science Advisory Panel "The Impact of Cruise Ship Wastewater Discharge on Alaska Waters" November 2002, Section I located at http://www.state.ak.us/dec/press/cruise/documents/impact/dilutionwastewater.htm

[67] Figures taken from Wilderness Discoverer 2003 VSSP. Small ship water production varies with ship capacity and configuration.

During stationary discharge, small ship effluent may pose a risk to human health in areas where aquatic life is harvested for raw consumption due to the high concentration of fecal coliform.

6. EVALUATION OF WASTEWATER TREATMENT TECHNOLOGY

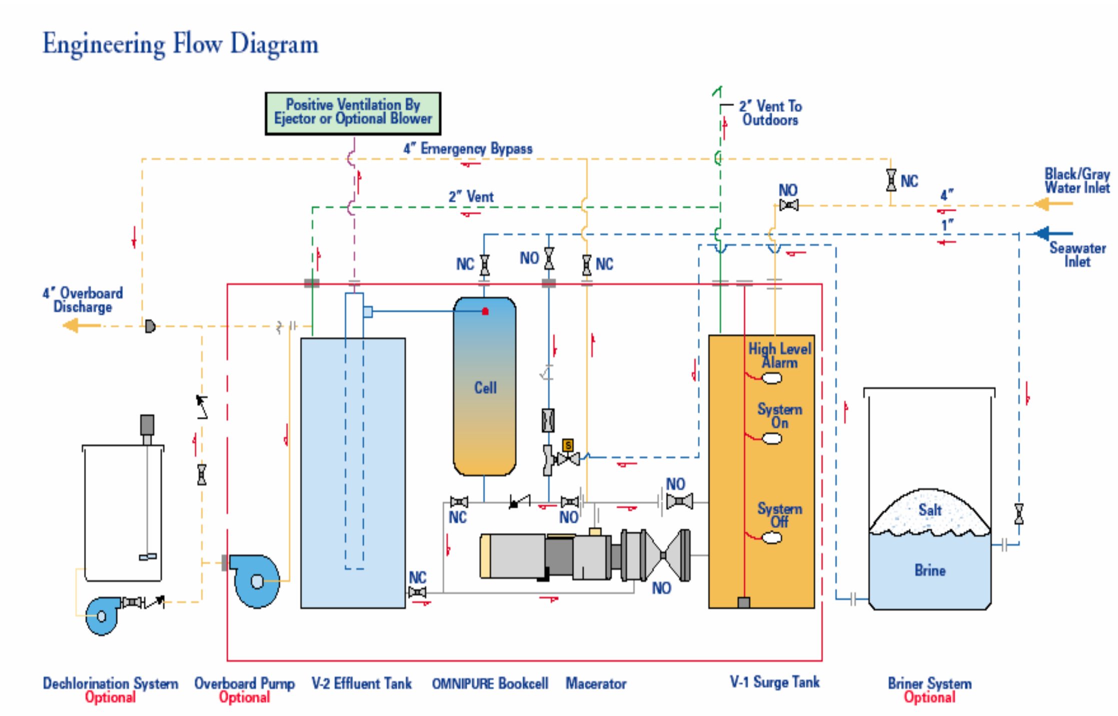
6.1. TRADITIONAL TREATMENT SYSTEMS

Prior to 2001, vessels used one of two marine sanitation devices (MSDs) to treat sewage on ships: maceration-chlorination or biological-chemical disinfection systems.

Maceration-chlorination systems

Maceration-chlorination systems are installed on most of the small cruise ships and ferries that ply Alaska waters.[68] This system reduces bio-solids through maceration, internal dilution, oxidation, and chlorine disinfection. The macerator pump breaks up solids in the sewage influent to a maximum particle size of 1.5 mm. The wastewater is then mixed with ambient seawater and passed between charged cell plates where a number of reactions occur simultaneously. The reactions cause the electrolytic breakdown of organic molecules. The electrocatalytic process also produces sodium hypochlorite from the salt in the seawater. This disinfectant continues to oxidize the waste stream in a contact tank with a 90-95% oxidation rate that kills total bacterial within minutes.[69] The treated water remains in the contact tank, usually for a minimum of 30 minutes. In low salt brackish water, some operators add chlorine to the tank to ensure disinfection is complete or add salt to the waste stream. Material that is not oxidized (i.e. cellulose) is returned for further treatment. No sludge is produced. Gases produced from reactions are mixed with ambient air and exhausted. (Figure 3.)

Figure 3. Maceration-Chlorination System



[68] ADEC, 2003 Small Commercial Passenger Vessel Wastewater Treatment Table, http://www.state.ak.us/dec/press/cruise/documents/2003smallshiptable.htm
[69] Information from Exceltech website http://www.21mainstreet.com/alpha/exceltec.asp

Maceration-chlorination systems often produce effluent that does not meet the Alaska commercial passenger vessel fecal coliform standard. (See Section 4 "Wastewater Characteristics - Small Ships.") Another disadvantage of this system is that operators tend to chlorinate in excess of the manufacturer's recommendations in order to meet this standard. Marine life is very sensitive to chlorine. The chlorine concentration in ambient water must be less than 7.5 ug/l to protect aquatic life.[70] Whole Effluent Toxicity (WET) Testing conducted in July 2002 demonstrated that chlorine level in wastewater effluent can be toxic to marine life.[71]

Alaska Marine Highway System (AMHS) ferries present an interesting case study on the importance of properly operating maceration-chlorination systems as well as sampling in the proper location in the treatment cycle. In April 2002, AMHS engineers discovered that their wastewater had been sampled before it had sufficient chlorine contact time, and subsequently began sampling in the correct location. This explains the high geometric mean of fecal coliform in samples taken prior to May 1, 2002 (4,212 MPN/100 ml) versus those samples taken during the remainder of 2002 (94 MPN/100 ml).[72] (See Table 19.) Samples taken from May through December 2002 also had lower chemical oxygen demand (COD) and total suspended solids (TSS) and higher chlorine residual.

In 2003 however, wastewater samples had the highest level of fecal coliform and lowest level of chlorine of all three years. ADEC audited the samplers during a July 29, 2003 sampling event. The sampler took the sample 15 minutes into the pumping cycle and the fecal coliform result was 11,000 MPN/100 ml. This seems to suggest that the timing of the sample did not make any difference as was suggested comparing the 2001 with the 2002 data. The AMHS information indicates that maceration-chlorination treatment systems are sensitive devices that produce variable results depending upon operation. However, the 2002 data demonstrated that maceration-chlorination systems can achieve fecal coliform levels that are in compliance with the state cruise ship law.

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[70] ADEC Saltwater Aquatic Life Criteria Comparison http://www.state.ak.us/dec/dawq/wqs/documents/saltwateraquaticlifecriteria.htm
[71] The Science Panel interpretation of the WET test is located at http://www.state.ak.us/dec/press/cruise/documents/wetfinal.htm. The laboratory results for the WET test are located at http://www.state.ak.us/dec/press/cruise/documents/wetreport.htm.
[72] This number is different than the number in Section 9 of "The Impact of Cruise Ship Wastewater Discharge on Alaska Waters" November 2002 by Science Advisory Panel. ADEC wrote Section 9 with all sampling data received by September 30, 2002. This report includes additional data points for 2002.

Table 19. Alaska Marine Highway System Samples

All values are medians except fecal coliform which is expressed as a geometric mean.

Date (Table in Appendix E)	Number of Samples	Total Ammonia as N	BOD 5-Day	COD	Fecal coliform	Free chlorine	pH	Total chlorine	TSS
		mg/L	mg/L	mg/L	MPN/100 ml	mg/L		mg/L	mg/L
	MDL	0.03	2.0	3.0	2	0.10	0.1	0.10	1.3
January 2001 - April 2002 (Table 38)	8	7.61	99	765.0	4,212	0.55	7.5	1.10	89.4
May 2002 - December 2002 (Table 37)	10	9.50	102	557.0	94	2.25	7.5	1.78	64.8
January – December 2003 (Table 36)	9	11.00	185	365.0	13,990	0.00	7.2	0.00	99.2

Biological And Chemical Disinfecting Systems

Marine biological treatment systems are similar to land based municipal treatment systems. A marine biological treatment system has three steps: (1) aeration; (2) clarification & filtration; and (3) final chemical disinfecting.[73] All sludge is re-circulated to the activated sludge aeration section.[74]

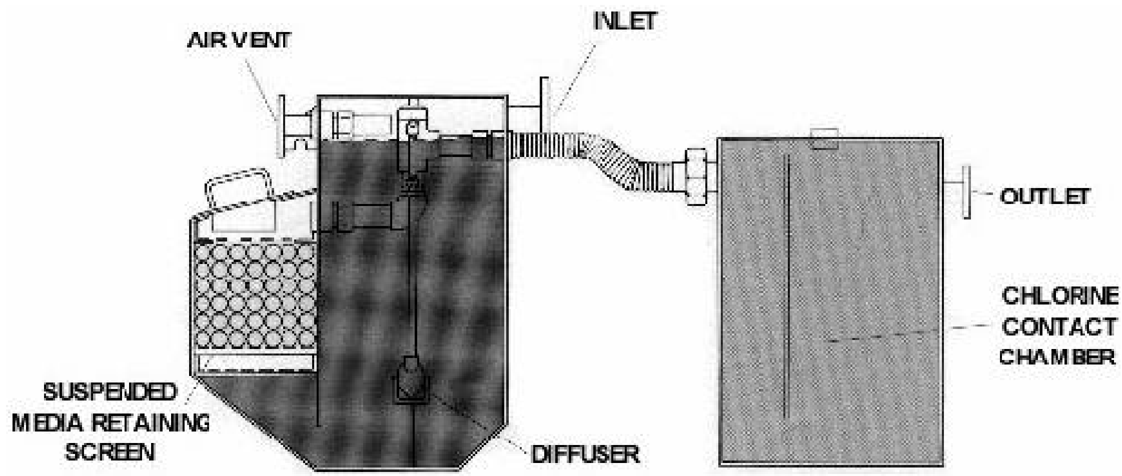
The raw sewage passes through a screen, which removes grit, then enters the marine sanitation device (MSD) aeration chamber. The raw sewage mixes with a large concentration of active aerobic bacteria that consume the organic waste in the sewage. The chamber contains air diffusers that provide oxygen to keep the aerobic bacteria healthy.

The wastewater flows from the aeration chamber into the clarification and filtration chambers. The filter media removes larger pieces of organic waste not consumed by bacteria in the aeration chamber. The aerobic bacteria also consume the biomass on the filter. After clarification and filtration, wastewater flows into the chlorine contact chamber. The wastewater stays in this chamber until virtually all bacteria are killed resulting in a chlorine residual of 1 – 2 mg/l (ppm).

Unlike a land based biological system, marine systems process a concentrated blackwater stream without dilution from graywater or storm water. Biological systems thrive on a constant, even flow of nutrients and constant pH. This constant flow is difficult to achieve since the demand on a ship's treatment system is intermittent with periods of low or no flow.

[73] Fox-Pac MSD home page http://www.redfoxenviro.com/foxpacmarinemsd.html
[74] Waste treatment systems: http://www.hamworthykse.com/docGallery/29.PDF

Figure 4. Biological and Chemical Disinfection System[75]



6.2. Advanced Treatment Systems

The fecal coliform and total suspended solids standards in the state and federal cruise ship laws have prompted large ships to either install advanced treatment systems that meet secondary treatment standards or to hold all of their wastewater for discharge outside of Alaska. Large cruise ship operators have evaluated several advanced wastewater treatment designs. These include chemical treatment and mechanical decanting; activated oxidation and oxidant disinfection; reverse osmosis filtration, and bio-reactor/filtration. The overall value and efficiency of each system, which includes evaluation of the installation cost, maintenance, operator training and monitoring, continues to be a subject of research by the cruise lines.

Generally, cruise ships using advanced technology have combined enhanced aerobic digestion with filtration to clean shipboard wastewater. These treatment systems do not use chlorine in the normal treatment process; however, some ships may use chlorine to control fecal re-growth that occurs in the discharge piping.

These treatment systems all produce solid sludge, which is discharged 12 miles from shore, incinerated, or offloaded it to land based disposal sites.

<u>Chemical treatment and mechanical decanting</u>

This system uses chemical treatment and a mechanical decanter, followed up by a UV purifier. The design is used successfully in shore-based applications and showed promise in large-scale laboratory tests. However, the pilot program on a cruise ship indicated that modifications were necessary for a fully operational treatment system.[76] No additional information is available to ADEC on this system.

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[75] Fox-Pac MSD home page http://www.redfoxenviro.com/foxpacmarinemsd.html
[76] From a wastewater technology paper prepared by David Eley for the Governor's Briefing Papers and Alaska Regional Response Team updated June 2002. For more information contact Mr. Eley at 907-586-2685 or capedec@alaska.com

Activated Oxidation Process

This treatment process is currently operated on ten small ferries in British Columbia.[77] It has four major components: (1) a primary screening system, (2) a primary solids separation and oxidizing system, (3) a secondary oxidation tank, and (4) oxidant generation equipment, which eliminate the need for chlorine disinfection. Ozone disinfection presents fewer known environmental and health effects than chlorine and its byproducts.[78] It is more effective than chlorine at killing bacteria and viruses. In addition, ozone is unstable in the environment and decomposes to oxygen in a short period of time.[79]

An enhanced system with a biological oxidation component has been installed on Royal Caribbean's *Vision of the Seas*.[80] A polymer is also added to the preliminary stage to cause the solids to clump together and for a sludge "mat". The process removes the mat before the effluent enters the treatment system.[81] The treatment system is comprised of six main system components: (1) primary solids separation/oxidation tank; (2) bioreactors (Hydroxyl-F^3R); (3) secondary solids separation; (4) oxidation/disinfection tank; (5) controls and oxidant generation equipment; and (6) sludge dewatering and drying equipment.

The sludge is dewatered and incineration onboard or offloaded to shore. No discharge at sea is necessary. The system manufacturer is conducting tests on the *Vision of the Seas* to ensure that it meets U. S. Coast Guard discharge standards for stationary discharge in Alaska. ADEC has not yet received wastewater effluent data from this system.

Reverse Osmosis Filtration

Osmotic theory dictates that pure water will move across a semi-permeable membrane into wastewater until the contaminant concentrations of both liquids are equal. However, if external pressure is exerted on the contaminant solution, water will flow in the reverse direction from the wastewater into the pure water. This phenomenon is known as reverse osmosis (RO). Reverse osmosis treatment systems have been installed on two ships[82] operating in Alaska. Both systems use ultraviolet (UV) disinfection after the RO unit and were approved by the U.S. Coast Guard for stationary discharge during 2003. The effluent from both systems has a slightly low pH which requires some buffering. *Mercury's* treatment system includes a final run through activated charcoal canisters before discharge. The sample points are both ships are less than 50 feet from the overboard discharge point.

[77] Hydroxyl Systems B.C Ferry Services Inc. case study website: http://www.hydroxyl.com/marine/index.html
[78] EPA/625/1-86/021 EPA Design Manual Municipal Wastewater Disinfection
[79] EPA 832F99063, EPA Ozone Fact Sheet, September 1999. http://www.epa.gov/npdes/pubs/ozon.pdf
[80] Hydroxyl Systems *Vision of the Seas* case study website: http://www.hydroxyl.com/marine/index.html
[81] Hydroxyl system described on website http://www.hydroxyl.com/index.html
[82] Celebrity *Mercury* blackwater and Carnival *Spirit* graywater

Table 20. Samples Taken after RO/UV Treatment Unit (2003)

	pH	BOD5	TSS	total chlorine residual	free chlorine residual	fecal coliform
Number of Samples = 21		mg/L	mg/L	Mg/L	mg/L	MPN/100
Minimum	6.6	0	0.0	0.00	0.00	0
Median	7.3	15	0.0	0.00	0.00	0
Maximum	9.1	27	0.0	0.00	0.00	4

Large Ship Sampling Data Appendix B, Table 5

Bio-reactor/filtration

These units employ an integrated system of enhanced aerobic digestion and low-pressure membrane filtration to treat blackwater and graywater. Currently, sixteen large cruise ships operating in Alaska have installed this process using Zenon, Scanship, or Hamworthy systems.[83]

After only a brief holding period in the bio-reactor, the Zenon system passes the influent through membrane filtration modules that have very large surface area and an extremely small pore size (0.035 micron or 0.035 X 10^{-6} meters).[84] Wastewater then passes through a UV disinfection unit. Samples are taken immediately after the UV unit. The distance from the UV unit to the discharge point varies from vessel to vessel.

Table 21. Zenon/UV Treatment System (2003)[85]

Number of Samples = 24	pH	BOD5	TSS	Total Chlorine Residual	Free Chlorine Residual	Fecal Coliform
Units		**Mg/L**	**mg/L**	**mg/L**	**mg/L**	**MPN/100**
Minimum	7.2	0	0.0	0.00	0.00	0
Median	7.6	0	0.0	0.00	0.00	0
Maximum	8.4	5	0.0	0.00	0.00	0

Large Ship Sampling Data Appendix B, Table 6.

The Scanship system relies more heavily on biological digestion. This unit enhances the capacity and effectiveness of the bio-reactor with plastic carrier elements (biofilm) suspended in the wastewater to increase reactor surface area with eventual polishing microfiltration and UV

[83] ADEC, 2003 Large Commercial Passenger Vessels Discharge Status and Wastewater Treatment, http://www.state.ak.us/dec/press/cruise/documents/2003largeshipwwtable.htm

[84] From a wastewater technology paper prepared by David Eley for the Governor's Briefing Papers and Alaska Regional Response Team, updated June 2002 and discussions with Rick Softye former VP of Holland America.. For more information contact Mr. Eley at 907-586-2685 or capedec@alaska.com.

[85] Holland America *Maasdam, Ryndam, Statendam, Veendam, Volendam*, and *Zaandam*

disinfection.[86] At the beginning of the season, samples were taken after the UV. By mid-season, the samples were taken at the end of the discharge line before the overboard port.

Table 22. Scanship/UV (2003)[87]

Number of Samples = 18	pH	BOD5	TSS	Total Chlorine Residual	Free Chlorine Residual	Fecal Coliform
Units		**mg/L**	**mg/L**	**mg/L**	**mg/L**	**MPN/100**
Minimum	6.3	5	0.0	0.00	0.00	0
Median	6.9	11	7.0	0.00	0.00	0
Maximum	7.6	26	28.6	0.00	0.00	240

Large Ship Sampling Data Appendix B, Table 7

In a Hamworthy system, wastewater is passed through an aerobic biological treatment system and ultrafiltration units. It is then chlorinated to kill remaining bacteria. The chlorine levels in the effluent were occasionally over the 10 mg/l limit for continuous discharge allowed by the U.S. Coast Guard and the Alaska Water Quality Standard of 7.5 ug/l. Princess has installed UV on two of their ships with the Hamworthy system and is considering substituting UV for chlorine disinfection on all ships in the future. Samples of this system were taken on the discharge line near the overboard port. Some samples indicated that there was fecal contamination within the discharge line.

Hamworthy (2003)[88]

Number of Samples = 58	pH	BOD5	TSS	Total Chlorine Residual	Free Chlorine Residual	Fecal Coliform
Units		**mg/L**	**mg/L**	**mg/L**	**mg/L**	**MPN/100**
Minimum	6.6	0	0.0	0.00	0.00	0
Median	7.3	2	0.0	0.00	0.00	0
Maximum	8.1	86	19.1	55.00	50.00	220

Large Ship Sampling Data Appendix B, Table 8.

All four of the treatment systems listed above regularly satisfy the requirements necessary to maintain U.S. Coast Guard continuous discharge certification. (See Table 2.)

[86] Scanship Environmental website: http://www.scanship.no/
[87] Norwegian *Sky, Sun*, and *Wind*
[88] Princess *Dawn, Island, Pacific, Star* and *Sun;* Radisson *Seven Seas Mariner*

Table 23. Comparison of Advanced Treatment System Medians

Number of Samples = 58	pH	BOD5	TSS	Total Chlorine Residual	Free Chlorine Residual	Fecal Coliform
Units		**mg/L**	**mg/L**	**mg/L**	**mg/L**	**MPN/100**
RO (21)	7.28	14.9	0.0	0.00	0.00	0
Zenon (24)	7.64	0.0	0.0	0.00	0.00	0
Scanship (18)	6.94	10.9	7.0	0.00	0.00	0
Hamworthy (58)	7.33	2.2	0.0	0.00	0.00	0

Sample data demonstrated that fecal coliform contamination of the effluent sometimes occurred in the discharge pipe. The probability of fecal contamination increased as the pipe length increased. ADEC will therefore require that samples be taken within 50 feet of the overboard discharge location in the future.

7. RISK CHARACTERIZATION

7.1. Toxicological Profile of Detected Pollutants

Sections 3 and 4 discuss the large ship and small ship wastewater data. Table 11 and Table 16 list the pollutants that exceed water quality standards in receiving water. This section will discuss those pollutants in greater detail.

CONVENTIONAL POLLUTANTS

Ammonia

Ammonia is present in two forms in saltwater: un-ionized ammonia (NH_3) and the ammonium ion (NH_4+). The un-ionized ammonia form has been demonstrated to be the more toxic form of ammonia.[89] Ammonia affects the life cycle as well as survival of some species.[90] Water quality parameters, particularly pH and temperature, but also salinity, affect the proportion of un-ionized ammonia.

Ammonia at concentrations slightly less than those chronically toxic to animals may stimulate growth and reduce reproduction of a red macroalgal species.[91]

Ammonia has a strong and suffocating odor. Ammonia's short term human health effects include lung irritation, causing coughing and/or shortness of breath. Higher exposures cause fluid buildup in the lungs (pulmonary edema), which can cause death. In addition, ammonia is a corrosive chemical, which can severely burn the eyes and skin. Repeated exposure to ammonia can cause chronic irritation of the eyes, nose, mouth, and throat.

Chlorine

Free residual chlorine is described as the portion of the chlorine injected into water that remains as molecular chlorine, hypochlorous acid, or hypochlorite ions after the solution has reached a state of equilibrium. Combined residual chlorine is described as the portion of chlorine injected into water that remains combined with ammonia or nitrogenous compounds after the equilibrium has been reached. Both free and residual chlorine have a very short half-life in marine waters; therefore, it is difficult to assess the effects of chlorine on aquatic life.[92] ADEC saltwater criteria for chlorine are 13 µg/L (acute criterion) and 7.5 µg/L (chronic criterion).[93]

In humans, ingestion of large doses of chlorine may cause gastrointestinal irritation, including vomiting and nausea. If dehydration occurs, body temperature increases and circulatory and central nervous system damage may result. Exposure of the eyes to sodium chloride may cause

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[89] EPA 440/5-88-004 Ambient Aquatic Life Water Quality Criteria. page 7

[90] Details of the testing results is located in EPA 440/5-88-004 located at http://www.epa.gov/waterscience/pc/ambientwqc/ammoniasalt1989.pdf

[91] EPA 1989, Ambient Water Quality Criteria for Ammonia (Saltwater)-1989, EPA Office of Water, Regulations and Standards Division, Washington DC, EPA 440/5-88-004

[92] EPA January 1985, Ambient Water Quality Criteria for Chlorine, Office of Water, EPA 440/5-84/030

[93] ADEC, Alaska Water Quality Criteria Manual for Toxic and other Deleterious Organic & Inorganic Substances, May 15, 2003, Table IV or V available at http://www.state.ak.us/local/akpages/ENV.CONSERV/dawq/wqs/pdf/70wqsmanual.pdf

stinging while exposure to other forms of chlorine, including free and residual chlorine, may cause stinging or irritation of the skin.

Fecal Coliform

Bacteria water quality standards are set to protect human health from diseases associated with water that has been contaminated with feces. The presence of fecal coliforms usually indicates the presence of pathogens. Shellfish concentrate fecal coliform bacteria and other pathogens that may be present with coliform bacteria. Shellfish beds are closed to harvesting when the geometric mean of fecal coliform bacteria exceeds 14 colonies per 100 milliliters of water. While most fecal coliform bacteria are harmless to humans, exposure to some may cause short-term adverse effects, including rash, ear infections, gastrointestinal pain, nausea, diarrhea, vomiting, and fever.[94]

PRIORITY POLLUTANTS

Copper

Copper is highly toxic in aquatic environments. Copper will bio-concentrate in many different organs in fish and mollusks. Copper is an effective algaecide. Free ions of copper are the lethal agent. Single cell and filamentous algae and cyanobacteria are more susceptible to the acute effects, which include reductions in photosynthesis and growth, loss of photosynthetic pigments, disruption of potassium regulation, and mortality. Mammals are not as sensitive to copper as are other aquatic organisms. The predominant mammalian effects include hepatic and renal toxicity, and fetal mortality.[95] However, high doses are usually required to elicit these effects in mammals.

Alaska has a water quality standard of 3.1 µg/L dissolved copper in saltwater based on chronic effects to aquatic life.

Low levels of copper are essential for humans. Exposure to high levels of copper may cause mouth and eye irritation and may induce vomiting, nausea, and intestinal pain.[96]

Zinc

Zinc is very soluble in water and is almost never found free in nature. It is one of the most mobile of the heavy metals. Most of the zinc introduced into the aquatic environment is partitioned into the sediments by sorption onto hydrous iron, manganese oxides, clay, and organic materials.[97] Variables affecting the mobility of zinc include the concentration and composition of suspended and bed sediments, dissolved and particulate iron and manganese concentrations, pH, salinity, concentration of ions or molecules that bind to transition-metal ions, and the concentration of zinc.

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[94] Washington State Department of Ecology, March 2002, *Focus: Fecal coliform bacteria and Washington's water quality standards*, Publication No. 02-10-010.

[95] EPA, 2002a, National Recommended Water Quality Criteria – Correction, EPA Office of Water, Washington, DC, EPA 822-Z-99-001.

[96] Agency for Toxic Substances and Disease Registry (ATSDR), United States Department of Health and Human Services, Center for Disease Control, September 2002, ToxFAQs for Copper.

[97] EPA 440/5-87-003 EPA Ambient Water Quality Criteria for Zinc February 1987.

Most organisms need some minimum concentration of zinc to function properly. Toxicity of zinc to an organism depends on feeding habits. Plants and most fish would not be adversely affected, but many invertebrates could be affected by ingestion of sufficient quality of particulates containing zinc. The toxicity of zinc, as well as other metals, is reported to be influenced by a number of chemical factors including cadmium, magnesium, hardness, pH, and ionic strength. These factors appear to affect the toxicity of zinc by influencing the proportion of available zinc or by inhibiting the sorption or binding available by biological tissues. Alaska has a water quality standard of 81.0 µg/L of dissolved zinc in saltwater based on chronic effects to aquatic life.

As with copper, zinc is an essential element in humans at low doses. Human ingestion of zinc is generally not a concern. The Recommended Daily Allowances for adults is 15 mg/day.[98]

7.2. Cumulative Impact

Large Ships

Since the passage of the Alaska cruise ship laws, large cruise ships installed advanced wastewater treatment systems that meet the stringent U.S. Coast Guard requirements for continuous discharge. The quality of the wastewater on large ships has therefore improved dramatically. During 2003, all the large cruise ships that discharged wastewater in Alaska had these advanced systems. Ships that did not have advanced systems discharged outside 3 nautical miles. The 2003 data is the most representative of the wastewater quality that ADEC expects in the future. Therefore, we will focus on the risks presented by the 2003 data.

In 2003, ships were sampled for 16 conventional pollutants and 160 priority pollutants. **The vast majority of these pollutants were not detected.** Only ammonia, copper, nickel, and zinc did not regularly meet Alaska Water Quality Standards at the end of pipe (Table 10).

The Science Advisory Panel concluded in *The Impact of Cruise Ship Wastewater Discharge on Alaska Waters* that effluent from a typical large ship will be diluted by a factor of at least 50,000 during underway discharge.[99] By applying this dilution factor, the concentration of all pollutants would meet Alaska Water Quality Standards in the receiving water during underway discharge.

ADEC was concerned about the impacts on the receiving water caused by stationary wastewater discharge. In order to address this issue, ADEC calculated the dilution factor during stationary discharge for each large ship during a worst case scenario. (See Appendix D Cruise Ship Stationary Discharge Modeling for more information.) The lowest dilution value for each effluent type was then used to calculate the anticipated concentration of each pollutant in receiving water during stationary discharge (Table 11). After applying the dilution factor, no tested pollutant would exceed Water Quality Standards.

Whole Effluent Toxicity (WET) testing was done in 2003 on 4 of the 18 large ships that discharged in Alaska. Test results indicate that **wastewater effluent from large ships with advanced wastewater treatment systems does not pose a risk to aquatic organisms, even**

[98] EPA 440/5-80-079 October 1980 Ambient Water Quality Criteria for Zinc.
[99] Science Advisory Panel "The Impact of Cruise Ship Wastewater Discharge on Alaska Waters," November 2002 http://www.state.ak.us/dec/press/cruise/documents/impact/dilutionwastewater.htm

during stationary discharges. ADEC will continue WET testing on the advanced wastewater treatment systems during 2004. This test gives insight into the wastewater's effect on marine organisms. This test indicates that exceedances of ammonia, copper, nickel and zinc Water Quality Standards at the end of pipe are not harming aquatic life.

None of the pollutants mentioned above are present in concentrations should cause risks to human health.

Small Ships

ADEC reviewed data collected from small commercial passenger vessels from 2001 through 2003. These ships have not installed new wastewater treatment systems on their vessels and the effluent quality has remained relatively consistent.

During the evolution of the sampling protocol, pollutants have been added and deleted as appropriate. In 2003, ships were sampled for 16 conventional pollutants and 160 priority pollutants. **The vast majority of these pollutants were not detected**. The eight (8) pollutants that did not regularly meet Alaska Water Quality Standards at the end of pipe are included in Table 15.

The Science Advisory Panel concluded that the dilution factor caused by the underway discharge by a small ship would be based on the width, draft, and speed of the vessel divided by the discharge rate and multiplied by a factor of 3.[100] With the aid of this dilution, we would expect all pollutants to meet Alaska Water Quality Standards during underway discharge.

ADEC was concerned about the impacts on the receiving water caused by stationary wastewater discharge. In order to address this issue, ADEC calculated the dilution factor caused by stationary discharge for each small ship during a worst case scenario. (See Appendix D Cruise Ship Stationary Discharge Modeling for more information.) The lowest dilution value for each effluent type was then used to calculate the expected concentration of each pollutant in receiving water during stationary discharge (Table 16). Even with the benefit of dilution, we predict the stationary discharge of wastewater from small ships contain concentrations of free chlorine, fecal coliform, copper, and zinc that exceed Alaska Water Quality Standards.

The marine environment is very sensitive to the concentrations of free chlorine. In fact the water quality standards are below the methods of detection for chlorine. The concentration of chlorine in mixed blackwater and graywater during 2002 was found in excess of 100 times the Alaska Water Quality Standards. The predicted concentration of chlorine from this discharge was 10 times the standard in receiving water and therefore did pose a risk to aquatic life during stationary discharges.

The fecal coliform concentrations in receiving water indicate that it is important for these ships to avoid anchoring in areas used for shellfish aquaculture or areas frequently used for subsistence and recreational shellfish harvesting. Most of the shellfish farms in Southeast Alaska are located between Ketchikan and Petersburg. ADEC evaluated the small ship routes and the location of

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[100] The Science Panel has developed a formula for predicting dilution/dispersion in the wake of small cruise ships.
Dilution factor = 3 x (ship width x ship draft x ship speed)/(volume discharge rate);
http://www.state.ak.us/dec/press/cruise/documents/impact/dilutionwastewater.htm

registered commercial shell fish beds and found that small ships do not currently moor or dock near these sites.

Copper is highly toxic in aquatic environments. This toxicity is reflected in the low Alaska Water Quality Standard of 3.1 µg/L dissolved copper in saltwater. The predicted concentration of copper in receiving water during small ship stationary discharge can be as high as 10 times this standard and therefore does pose a likely risk to aquatic life.

Most organisms need a minimum concentration of zinc to function properly. Alaska has a water quality standard of 81.0 µg/L for dissolved zinc in saltwater based on chronic effects to aquatic life. In 2003, the level of dissolved zinc found in receiving water during graywater discharge slightly exceeds Water Quality Standards, and therefore poses some risk to aquatic life.

The Whole Effluent Toxicity (WET) testing done in 2002 and 2003 in conjunction with the information above indicates that **the wastewater effluent from small ships poses some risk to the marine environment during stationary discharges.**

The concentration of fecal coliform in the effluent during stationary discharge would pose a risk to human health in areas where aquatic life is harvested for raw consumption.

7.3. Comparison to other Marine Discharges

Cruise ship's wastewater systems can be compared to municipal treatment systems that serve small Alaskan cities. Cruise ships are excluded from obtaining permits under the Clean Water Act. However, their marine sanitation devices (MSDs) must meet effluent standards set in Section 312. This section set the Type II MSD standards for blackwater at 200 fecal coliform/100 ml and 150 mg/L total suspended solids (TSS). In Alaska, cruise ships must also adhere to state and federal wastewater effluent standards and discharge conditions (Table 2).

Municipalities must obtain permits under the Clean Water Act before discharging wastewater. The Act uses both water quality effluent standards and technology based limits to protect water quality.[101] It has been termed a technology-forcing statute because of the rigorous demands placed on the regulated community to improve effluent quality through treatment technology. The Act required municipalities to upgrade systems to secondary treatment, (85% removal of biological oxygen demand (BOD) and total suspended solids (TSS)), by July 1, 1988. Eighty-six percent (86%) of municipalities met that date. Cities that discharged wastes into the marine environment were eligible for case-by-case EPA waivers of the secondary treatment requirement. These waivers, referred to as 301(h) waivers, require 30% removal of BOD and TSS. In order to be eligible for these waivers, natural factors such as tides and currents must provide significant elimination of traditional forms of pollution, protect shell fish, fish, and other aquatic life, and comply with water quality standards. Waivers were only granted, with certain exceptions, if a waiver application was filed by December 29, 1982.

Juneau and most other Alaskan cities adhere to secondary treatment standards and have limits that do not allow the exceedance of a monthly geometric mean of 200 fecal coliforms per 100 ml if chlorine is used for disinfection and a monthly geometric mean of 400 fecal coliform bacteria if ultraviolet light is used for disinfection. However, many communities in Southeast Alaska including the popular cruise ship ports of Ketchikan, Skagway, and Sitka have waivers from

[101] Copeland, Claudia. CRS Report for Congress, Clean Water Act: A Summary of the Law, January 20, 1999

secondary treatment. These treatment systems have been assigned very large mixing zones to allow for dilution in the receiving water. These cities have effluent limits with a daily maximum of 1.5 million fecal coliforms/100 ml and a monthly geometric mean of 1 million fecal coliforms/100 ml. These are the highest limits that have been allowed in Alaska.

Domestic and industrial discharges in Alaska usually exceed water quality standards at the end of pipe. Under the State of Alaska and the National Pollutant Discharge Elimination System (NPDES) permit systems, these entities are granted mixing zones - areas where they may legally exceed water quality standards while dilution and decay or die-off occur. Outside of the mixing zone, water quality standards must be met. ADEC uses information from the discharge source such as wastewater volume, velocity, temperature, and salinity as well as pipe diameter and depth, and receiving water uses and sensitivity to determine the size of the mixing zone. These dischargers must monitor at the edge of mixing zone specified in their permit to ensure that they are meeting the water quality standards. Because other dischargers are typically granted a mixing zone, ADEC considered the effect of dilution on cruise ship effluent to assess its impact on water quality.

There are numerous potential sources of pollution that impact the Alaska marine environment. They include private vessels, commercial fishing vessels, day trip charter vessels, commercial passenger vessels that have less than 50 overnight passengers for hire, yachts, residential shore based dischargers, runoff and wildlife, (including marine animals). The effects of these other sources have not yet been quantified.

8. ADEC RECOMMENDATIONS

8.1. Recommendations for future study

Sampling

At the recommendation of the Science Advisory Panel, ADEC tested vessel wastewater for commonly used organophosphorus pesticides at the end of 2003 season. No pesticides were detected in the four samples. The ADEC will continue organophosphorus testing during the 2004 season.

Cyanide was dropped from the Quality Assurance/Quality Control (QAQC) Plan after 2000 even though there were high concentrations in some of the 2000 samples. We believe the exclusion from the sampling protocol was premature. ADEC will resume sampling for cyanide in 2004 when the state goes on board and samples the ship wastewater discharges.

In general, fecal coliforms survive for shorter periods than other enteric microorganisms in marine water. The absence of fecal coliform bacteria does not guarantee the absence of viruses and other pathogens.[102] EPA recommends using enterococci for bacteria monitoring in marine waters.[103] ADEC will sample vessel wastewater for *Escherichia coli* (E. *coli*) and enterococci, in 2004.

The current method detection limits (MDL) for chlorine exceeds Alaska Water Quality Standards. As part of the QAQC Plan for 2004, ADEC will require using a more sensitive test that can measure as low as 20 ug/l, instead of the current MDL of 100 ug/l. This sensitive method, however, will still not be able to detect the Alaska Water Quality chronic standard of 7.5 ug/l.

During 2003, some large ship samples were taken from the sampling port right after the treatment system but at a distance between 50 to 400 feet from the overboard discharge port. The 2003 data indicated that fecal contamination and growth occasionally occurs during the transit from the treatment system to the overboard port. In 2004, ADEC will only approve Vessel Specific Sampling Plans where samples are taken from sample ports located within 50 feet of the overboard discharge port.

State cruise ship regulations,[104] effective November 2002, allowed small ships to have a qualified crew member sample the vessel's wastewater. ADEC will encourage small vessel operators to use their own staff to sample their vessel as it comes into port. These samples will be more representative since ships will still be full with passengers and the treatment system will be operating normally. ADEC can provide sampling training to operators upon request. ADEC would audit the vessel samplers.

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[102] Commission on Geosciences, Environment and Resources, 1993 "Managing Wastewater in Coastal Urban Areas" pg. 67 http://books.nap.edu/books/0309048265/html/67.html

[103] EPA 440/5-88/007 Bacteria Water Quality Standards Criteria Summaries: A Compilation of State/Federal Criteria. September 1988.

[104] 18 AAC 69.090, http://www.state.ak.us/dec/title18/wpfiles/69mas.pdf

Section 5.1 discusses traditional treatment systems. The sampling results from the Alaska Marine Highway System (AMHS) ferries' macerator chlorinating systems were extremely variable from 2001 through 2003. ADEC recommends that AMHS sample for fecal coliform, total suspended solids (TSS) and chlorine at timed intervals such as: 1) at the discharge pump start; 2) 5 minutes into the pumping cycle; 3) 10 minutes into the pumping cycle; 4) 15 minutes into the pumping cycle; and 5) at the end of the discharge cycle. This experiment would check the fecal coliform variability throughout the pumping cycle. This information may indicate the correct location for the sample port in the treatment cycle.

New Studies

ADEC made assumptions about ambient water quality for the dilution model. It is important to check these assumptions with real data. ADEC will conduct ambient marine monitoring in Southeast Alaska in coordination with the Western States Coastal Environmental Monitoring and Assessment Program (EMAP) project during the summer of 2004.[105] The EMAP project will also include sediment and fish tissue sampling for heavy metals and PCBs. ADEC will use this information in future modeling efforts.

After applying the dilution factor calculated by the Visual Plumes model to effluent data, small ships exceed four Alaska Water Quality Standards (free chlorine, fecal coliform, copper, and zinc) in receiving water during stationary discharge. When a ship discharges above the waterline, the dilution factor is decreased, exacerbating the problem. The Visual Plumes model that is used to estimate the dilution factors in this report was not designed to model discharges from vessels. ADEC may perform a dye study in the future to determine the dilution factor caused by small ships during stationary discharge.

8.2. Recommendations for Best Management Practices

When large and small vessels discharge wastewater underway, they are able to meet all Alaska Water Quality Standards. The 2003 data indicates that large vessels with advanced wastewater treatment systems meet Alaska Water Quality Standards for all tested pollutants in receiving water during stationary discharges. Large vessels should use discharge ports that are less than 12 inches in diameter to create a jet like propulsion that will increase dilution. Large vessels should avoid discharging above the water line because this decreases dilution. ADEC also wants to encourage the continued use of ultraviolet light instead of chlorine as a disinfectant on large ships. It is also important that the discharge port be located within 50 feet of the wastewater treatment system to decrease the likelihood of fecal coliform contamination in the discharge line.

Small ships regularly exceed four Alaska Water Quality Standards in receiving water during stationary discharge. Vessels that have holding capacity should not discharge while stationary. Holding water while in port is ideal. Most small ships can hold their blackwater and mixed blackwater and graywater for up to 24 hours while stationary (Table 24). This is important since blackwater and mixed blackwater and graywater have the highest fecal coliform counts.

However, only one ship can hold their graywater, the majority of wastewater volume, for even 12 hours while stationary (Table 24). According to the Vessel Specific Sampling Plans,

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[105] For more information on EMAP, visit the EPA EMAP Research Strategy Report, July 2002 at: http://www.epa.gov/emfjulte/html/pubs/docs/resdocs/EMAP_Research_Strategy.pdf

graywater is not plumbed to blackwater holding tanks. Therefore, excess blackwater holding capacity can not be used to store graywater.

Small ships need to develop strategies to limit their graywater discharge while stationary. Small vessels should not do laundry to minimize their waste water production. Small vessels could also schedule to arrive in port or at anchor after the morning high water usage periods (8-10 a.m.) or leave before the evening high water usage (6-8 pm).

Table 24. Small Ship Holding Tank Capacity

Company	Ship Name	Number of passengers and crew	Blackwater (gallons per day)				Graywater (gallons per day)			
			Produced	Holding capacity	Hold 24hr	Hold 12 hr	Produced	Holding capacity	Hold 24hr	Hold 12 hr
AMHS	Columbia	223	6,690	23,800	Yes	Yes	GW is mixed with BW. See BW.			
AMHS	Kennicott	204	6,120	8,800	Yes	Yes	GW is mixed with BW. See BW.			
AMHS	Malaspina	188	5,640	8,006	Yes	Yes	GW is mixed with BW. See BW.			
AMHS	Matanuska	186	5,580	8,281	Yes	Yes	GW is mixed with BW. See BW.			
AMHS	Taku	97	2,910	3,360	Yes	Yes	GW is mixed with BW. See BW.			
Glacier Bay	Wilderness Adventurer	95	2,920	2,400	No	Yes	GW is mixed with BW. See BW.			
Glacier Bay	Wilderness Discoverer	120	3,130	2,400	No	Yes	GW is mixed with BW. See BW.			
America West Steamshp	Empress of the North	320	8,730	26,800	Yes	Yes	GW is mixed with BW. See BW.			
CruiseWest	Spirit of Discovery	105	500	1,700	Yes	Yes	2,500	30	No	No
CruiseWest	Spirit of Alaska	99	495	334	No	Yes	2,250	182	No	No
CruiseWest	Spirit of Columbia	99	400	3,600	Yes	Yes	2,260	478	No	No
CruiseWest	Spirit of Endeavour	130	600	934	Yes	Yes	3,600	934	No	No
CruiseWest	Spirit of 98	120	3,600	12,700	Yes	Yes	3,000	0	No	No
CruiseWest	Spirit of Oceanus	178	19,875	14,460	No	Yes	GW is mixed with BW. See BW.			
Lindblad	Sea Bird	96	3,000[106]	1,150	No	No	2,100	735	No	No
Lindblad	Sea Lion	98	3,000[107]	1,255	No	No	2,100	735	No	No
New World Ship Management	Clipper Odyssey	204	612	606	Yes	Yes	16,500	28,800	Yes	Yes
New World Ship Management	Yorktown Clipper	175	2,728[108]	2,996	Yes	Yes	12,000[109]	2,996	No	No

Source: Table created from information submitted by small ship owner and operators in their 2003 Vessel Specific Sampling Plans.

[106] Includes saltwater for flushing.
[107] Includes saltwater for flushing.
[108] Includes saltwater for flushing.
[109] This vessel does laundry which accounts for 2,000 gallons per day. This vessel should not do laundry in port.

8.3. Evaluation of Whether Small Ships Should Remain in the Program

Based on the wastewater testing results, ADEC recommends that small ships remain in the Commercial Passenger Vessel Environmental Compliance program. The Science Advisory Panel recommended in their November 2002 report that these ships should avoid stationary discharge, particularly in small fjords and embayments where the movement or flux of water is limited, because of the high levels of fecal coliform and suspended solids in their wastewater.[110] ADEC WET test results in conjunction with conventional and priority pollutant testing indicate that these small ships pose some risk to the marine environment during stationary discharge. Small ships that discharge blackwater or blackwater and graywater mixed while stationary may pose a risk to human health in areas where people collect shellfish for raw consumption.

Small vessels were granted three years to come into compliance with the state cruise ship law wastewater effluent standards.[111] As of March 1, 2004, these vessels may submit an interim protection plan that, if approved by ADEC, extends the time for compliance with the effluent standards. This plan should include a description of Best Management Practices, such as avoiding stationary discharges in areas of limited water movement, that the operator is undertaking to limit the adverse impacts of their discharges.[112] Violations and fines could be levied against ships that are found violating the terms of their approved plan.

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[110] Science Advisory Panel, November 2002, "The Impact of Cruise Ship Wastewater Discharge on Alaska Waters," Executive Summary, http://www.state.ak.us/dec/press/cruise/documents/impact/executivesummary.htm

[111] Alaska Statute 46.03.460 – 490 Section 7

[112] 18 AAC 69.045 Interim Protective Measures Plan, http://www.state.ak.us/local/akpages/ENV.CONSERV/title18/wpfiles/69mas.pdf