Alaska Department of Environmental Conservation
Commercial Passenger Vessel Environmental Compliance Program

2004 Whole Effluent Toxicity Discussion

Summary

The Alaska Department of Environmental Conservation (ADEC) conducted whole-effluent toxicity (WET) testing annually on selected vessels in 2002 through 2004. The ADEC selected vessels to evaluate different on-board treatment systems. In WET testing, a discharge's impact to the environment is evaluated in terms of its short (acute) or long-term (chronic) effects[1] on indigenous plant or animal species serving as test organisms. Test organisms are exposed to various concentrations of vessel wastewater samples and effects to those organisms are recorded. WET testing is an alternative to directly analyzing environmental samples for individual pollutants.

The WET tests performed in 2002[2] indicated that acute or chronic toxic effects on marine organisms are not expected when vessels discharge underway[3] because wastewater is mixed rapidly with the receiving water. ADEC designed the 2003 and 2004 WET test to determine whether there are any negative effects to the marine environment from stationary vessel discharges where wastewater is not rapidly mixed with the ambient water. For the 2003 and 2004 tests, ADEC modeled the vessel discharge dilution rate using the Environmental Protection Agency-approved model PLUMES using ambient conditions during a neap tide, or lowest tidal conditions for the month (i.e., a worst-case scenario). The PLUMES model was designed for discharges that occur under the waterline. This model calculates initial dilution as well as far field dilution.[4]

The 2003 WET results found that of the six ships tested, two large ships with advanced treatment systems (*Norwegian Wind* and *Ryndam*) and one small ship (*Spirit of Columbia'*s blackwater) with a traditional Marine Sanitation Device (MSD) showed no chronic or acute effects on marine organisms. Graywater results from one small ship (*Spirit of Columbia*) showed acute and chronic toxicity. One large ship with an advanced treatment system (*Sun Princess*) showed chronic toxicity. A small ship (*Spirit of Oceanus*) with mixed blackwater and graywater effluent did not show acute effects but did show some chronic toxicity to marine organisms.

The 2004 WET results indicate that most of tested wastewater effluent is not expected to cause acute toxicity to marine organisms, even at the worst-case scenario dilutions that occur during neap tides. *Kennicott* and *Veendam* effluent are not expected to cause either acute or chronic toxicity, even during neap

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[1] Effects include death or abnormal development.

[2] See Science Advisory Panel "Review and Comment Regarding Whole Effluent Toxicity Test Results for Five Commercial Passenger Vessels in Alaska July 2002" and "Lab results for Whole Effluent Toxicity test (WET)" report located at http://www.state.ak.us/dec/water/cruise_ships/reports.htm under **2002 Reports Available**

[3] The Science Advisory Panel estimated that the dilution behind a large cruise ship discharging at a rate of 200 cubic meters per hour and traveling at the minimum allowed speed of 6 knots will be greater than 50,000 to 1. Farfield dilution is conservatively estimated at 1:100. See "The Impact of Cruise Ship Wastewater on Alaska Waters" page x in Executive Summary. Report located at http://www.state.ak.us/dec/water/cruise_ships/reports.htm under **2002 Reports Available**

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

tides. *Spirit of Alaska* blackwater and *Summit* blackwater may cause chronic effects during neap tides. *Coral Princess's* mixed graywater and blackwater may cause adverse chronic effects on bivalve larvae development during neap tides. The *Spirit of Alaska's* graywater may cause both adverse acute and chronic effects during stationary discharge.

Vessels Selected

The ADEC selected the ships in the table below to represent the range of treatment systems used on both large and small commercial passenger vessels discharging into Alaska water.

Type (treatment)	2002	2003	2004
Large Ship[5] (Hamworthy)	*Dawn Princess*	*Sun Princess*	*Coral Princess*
Large Ship (Scanship)		*Norwegian Wind*	
Large Ship (other)			*Summit*
Large Ship (Zenon)	*Volendam*	*Ryndam*	*Veendam*
Large Ship (Rochem)	*Mercury*	*Carnival Spirit*	
Small Ship (traditional)	*Kennicott*	*Spirit of Oceanus*	*Kennicott*
Small Ship (traditional)	*Yorktown Clipper*	*Spirit of Columbia*	*Spirit of Alaska*

Methodology

The department hired and trained a contractor, Shannon & Wilson (S&W), to take effluent samples from four commercial passenger vessels and one state ferry operating in Alaska waters. S&W scheduled the sampling events in advance with the vessel operators. The sampling events took place during May and June 2004. S&W sent the samples to AMEC Earth and Environment Northwest Toxicology Laboratory located in Fife, WA (laboratory) within 24 hours of sampling. The laboratory was certified to conduct WET tests by the State of Washington's Department of Ecology. Conventional and priority pollutants were tested simultaneously and the results are found in Appendix A.

The laboratory analyzed the samples using test organisms selected by ADEC. The test species were selected because of their sensitivity and well-established testing protocols. The organisms selected were Mysid shrimp (*Mysidopsis bahia)* and Topsmelt (*Atherinops affinis).* Survival was evaluated after a 48-hour exposure period for the Mysid shrimp and a 96-hour exposure period for the Topsmelt. Chronic tests used the bivalve *Mytilus galloprovincialis* and the echinoderm *Strongylocentrotus purpuratus* and exposure periods of 96 hours and 40 minutes respectively.

The sampling, transporting, and testing met requirements of the project's Quality Assurance Quality Control (QAQC) plan followed standard EPA methods and met all test acceptability criteria with the following exceptions:

- The laboratory substituted a different organism (oysters) for the ADEC-selected bivalve (mussel) bioassay for the *Spirit of Alaska* because the mussels would not spawn. Oysters were not part of the

[5] Sampled graywater only in 2002. Hamworthy treating mixed blackwater and accommodations graywater sampled in 2003 & 2004.

project's QAQC plan and did not meet acceptance criteria during the test; therefore this test data cannot be used.

- The laboratory was unable to perform the bivalve chronic tests on the *Summit* sample because the bivalves failed to spawn and replacement organisms were not available.

The tests were run at six different concentrations of effluent to represent different dilutions. To simulate a range of conditions, including in-port discharges, ADEC requested the following WET dilution series for this test: 50%, 25%, 12.5%, 6.25%, 3.125% and 1.56%, control. This series represents concentrations that are attained in receiving waters with dilution factors of 2, 4, 8, 16, 32, and 64, respectively. A higher dilution factor means a lower concentration of effluent, and vice versa.

The WET test method can simulate different conditions of organism exposure. In a **static non-renewal test**, the test organisms are exposed to a single portion of the test solution for the duration of the test. In a **static renewal test**, the test organisms are exposed to new batches of the test water every day for the duration of the test. In a **flow-through test**, the test organisms are continuously exposed to new batches of test water. ADEC directed the lab to perform all WET tests using static renewal.

Effect of the exposure is measured in terms of a "no observable effect concentration" (NOEC) and a "lowest observable effect concentration" (LOEC) based on whether there is a statistical difference between controls and test samples. Additionally, a lethal concentration (LC) or a dose response curve can be calculated from the test results. LC is the concentration of the test material that kills a specified percentage of the test organisms over the observation time. For example, a "48-hr LC_{50}" is the concentration of the test sample that resulted in death of 50% of the organisms after a 48-hour exposure. ADEC uses the NOEC to evaluate ship discharges. Concentrations below NOEC pose no risk whereas concentration above NOEC show some effects and will be evaluated further.

Modeling Discharges from Vessels

In 2003, ADEC modeled individual ships' dilution factors using the PLUMES model in Skagway, Juneau and Ketchikan during a slack tide of a neap tide without wind effects such as waves or current shear, which may enhance mixing. The ambient waters with the least mixing occurred in Skagway. Therefore, ADEC used Skagway again in 2004 as the receiving waters. ADEC uses individual ships' dilution factors along with the ship's WET testing results to determine whether any toxic effects occur during neap tides.

One ship, the *Spirit of Alaska*, discharges graywater above the waterline. PLUMES, by design, cannot calculate dilution of discharge that occurs above the waterline. In order to apply the PLUMES model to *Spirit of Alaska* discharge, ADEC consulted with oceanographic modelers who suggested treating ships that discharge above the waterline as if they were discharging 6 inches below the waterline. The ADEC used this methodology.

Some of the individual ships' dilution factors are low. Ports and harbors are designed to have minimum wave action, which therefore reduces far-field dilution effects. Stationary vessels have a boundary layer around the hull that decreases the discharge's momentum to "break" through this boundary layer. Docks where vessels are tied up can also trap wastewater effluent and prevent it from mixing with ambient marine water. The effluent's temperature and salinity affect its density and how it disperses into the ambient

water. The ADEC plans to conduct a dye study during the 2005 season to determine how much these factors affect dilution of small ship discharges.

What are the Test Results?

Table 1 shows the results of the 2004 WET test bioassays. For simplicity, ADEC used as a benchmark the "no observable effects concentrations" (NOEC). This methodology is consistent with the 2002 and 2003 analysis. At concentrations above the NOEC listed, the effluent can be assumed to have an effect. The effluent is considered to have no effect at concentration below the NOEC listed.

Table 1: 2004 WET Results showing no observable effect concentration (NOEC) in percent effluent

Vessel	Effluent Type	Treatment System	Mysid Acute NOEC	Topsmelt Acute NOEC	Bivalve Larvae NOEC		Echinoderm Fertilization NOEC
					Normality[6]	Survival	
Spirit of Alaska	Blackwater	Macerator/ Chlorinator	6.25%	6.25%	Unusable data	Unusable data	<1.56%
Spirit of Alaska	Graywater	Untreated	12.5%	6.25%	Unusable data	Unusable data	3.125%
Kennicott	Mixed Blackwater & Graywater	Macerator/ Chlorinator	50%	50%	25%	50%	12.5%
Summit	Blackwater	Lazarus system/filtration	12.5%	25%	Unable to run[7]	Unable to run	1.5%
Veendam	Mixed Blackwater & Graywater	Zenon	50%	50%	Not run [8]	Not run	Not run
Coral Princess	Mixed Blackwater & Accommodations Graywater[9]	Hamworthy	50%	25%	3.125%[10]	12.5%	25%[11]

[6] Normality is the normal development of the bivalve larvae.
[7] Bivalves failed to spawn and test was not conducted.
[8] Per ADEC request, chronic tests were not conducted because no observable effects were observed from the highest concentration of wastewater from the Zenon system for the past two years.
[9] Laundry and galley graywater are discharged outside Alaska waters.
[10] *S. purpuratus* gametes were used for this analysis. They are not a bivalve, but they were substituted because the bivalves failed to spawn.
[11] The difference in echinoderm fertilization between the control (94%) and the 25% wastewater sample (88.2%) was less than 20%. This effects makes the NOEC is 25% instead of 12.5% to correct for the control being so close to the 25% wastewater sample.

Table 2 shows each sampled vessel's modeled dilution factors calculated by ADEC using the PLUMES model. The ambient conditions used are conditions experienced during a conservative neap-tide scenario. The table compares the vessel dilution factor to the dilution factor from the WET test series showing no observable effects concentration (NOEC). If the dilution factor of the vessel is smaller than the dilution that shows no observable effects, there may be some effect from that discharge. The ADEC highlights the tests that may cause effects.

Table 2: 2004 Vessel dilution factor compared with the dilution factor needed for no observable effect concentration (NOEC)

Vessel	Effluent Type	Dilution Factor[12]	Mysid Acute NOEC	Topsmelt Acute NOEC	Bivalve Larvae NOEC		Echinoderm Fertilization NOEC
					Normality[13]	Survival	
Spirit of Alaska	Blackwater	60[14]	16	16	Unknown	Unknown	>64
Spirit of Alaska	Graywater	4[15]	8	16	Unknown	Unknown	32
Kennicott	Mixed BW & GW	23	2	2	4	2	8
Summit	Blackwater	16	8	4	Unable to run[16]	Unable to run	64
Veendam Mixed Effluent	Mixed BW & GW	60	2	2	N/A	N/A	N/A
Coral Princess Mixed Effluent	Mixed BW & GW[17]	10	2	4	32	8	4

[12] See "Assessment of Cruise Ship and Ferry Wastewater Impacts in Alaska" at http://www.state.ak.us/dec/water/cruise_ships/assessreport04.htm in Appendix D.
[13] Normality is the normal development of the bivalve larvae.
[14] *Spirit of Alaska's* blackwater is discharged from a pump under the waterline, which increases dilution.
[15] Some of the *Spirit of Alaska's* graywater is discharged directly from drains by means of gravity and some graywater is discharged via a holding tank. The dilution factor was calculated based on discharge from the graywater holding tank at a rate of 2.5 gallons per minute.
[16] Bivalves failed to spawn and test was not conducted.
[17] This vessel treats graywater from accommodations only. Laundry and galley graywater are discharged outside Alaska waters.

What do the Test Results Mean?

Spirit of Alaska

The *Spirit of Alaska* discharges blackwater and graywater separately. A WET test was run on each stream.

Blackwater
The *Spirit of Alaska's* dilution factor in a worst-case scenario is adequate to protect sensitive marine organisms from acute toxic effects. The ADEC could not use the results from the bivalve chronic tests because the lab substituted the selected organisms with another species not included in the project's QAQC plan. Further, the substituted organism's control series did not meet the required acceptance criteria. The only chronic test with acceptable data is the echinoderm fertilization.

Using the PLUMES model, ADEC expects a dilution factor of 60 during stationary discharges and the echinoderm fertilization test show effects up to a dilution factor of 64. Based on the WET testing and modeling results, ADEC does not expect *Spirit of Alaska* blackwater discharge to cause acute toxic effects. The WET tests and modeling results do, however, indicate that *Spirit of Alaska* blackwater may cause chronic toxicity to marine organisms during neap tide events in Skagway. ADEC plans to test small ships such as the *Spirit of Alaska* for chronic toxicity in 2005.

Graywater
The worst case scenario dilution factor for graywater from the *Spirit of Alaska* is not adequate to protect sensitive marine organisms from acute and chronic toxic effects. *Spirit of Alaska's* graywater is discharged by gravity above the waterline. The sampled graywater was taken from a holding tank that was pumped overboard at 2.5 gallons per minute. The sample was taken while the ship was stationary. The ADEC, using the PLUMES model, expects a dilution factor of 4 when discharging into ambient water at neap tide. *Spirit of Alaska* graywater discharge may cause acute and chronic toxicity to marine organisms during neap tides events in Skagway. ADEC intends to perform a dye study in 2005 to evaluate the accuracy of the modeled dilution factors.

Kennicott

The *Kennicott's* dilution factor in a worst-case scenario exceeded the dilution required to produce no observable effects on the sensitive marine organisms tested during both the chronic and acute WET test. Based on the WET testing results and modeling, ADEC does not expect the *Kennicott* to cause acute or chronic toxic effects to marine organisms.

Summit

On the *Summit*'s test date the ship was certified by the USCG to discharge treated blackwater in port. The blackwater is treated with a dilution and filtration system. The graywater is discharged outside Alaska water and thus was not sampled. The ADEC calculated a dilution factor during stationary blackwater discharges of 16. While there would be no acute toxicity at this dilution, the WET tests show that the effluent exhibits some chronic toxicity on echinoderm fertilization at this dilution. The

analysis of the development of bivalve larvae was not conducted because the bivalves failed to spawn, and a replacement organism was not available.

Since the testing date, this system lost its certification to discharge blackwater continuously in 2004.

If discharging while in port, the effluent discharged may cause chronic toxicity to marine organisms during neap tides events in Skagway.

Veendam

The *Veendam's* dilution factor in a worst-case scenario exceeds the dilution required to produce no observable effects on the sensitive marine organisms tested during both of the acute WET tests. The ADEC had to remove one ship from chronic tests because the contract did not have enough funding and could not be extended because the Department contacts had ended. The ADEC selected the *Veendam* (which uses the Zenon advanced treatment system) because of the 2002 and 2003 results for the *Volendam* and the *Ryndam*, respectively (both using Zenon systems) showed that the dilution factor exceeds the dilution required to produce no observable effects for chronic WET testing. Based on the WET testing results and modeling, ADEC does not expect the *Veendam* discharge to cause acute or chronic toxic effects to marine organisms.

Coral Princess

The *Coral Princess'* dilution factor in a worst-case scenario exceeds the dilution required to produce no observable effects on both the acute tests and the echinoderm fertilization chronic test. ADEC does not expect the *Coral Princess* to cause any acute toxicity to marine organisms.

However, the modeled dilution at low tidal flow conditions is not high enough to protect against chronic effects on the normal development of the bivalve larvae.

In addition, the chronic tests from 2003[18] showed that the *Sun Princess*, which like the *Coral Princess* uses a Hamworthy treatment system, had similar effects on the development of bivalve larvae.

ADEC will continue to test this treatment system to determine what parameters in the effluent could be causing the toxicity to echinoderm and normal development of bivalve larvae.

Conclusions

1. Most of tested wastewater effluent is not expected to cause acute toxicity to marine organisms, even at the worst-case scenario dilutions that occur during neap tides. Focusing on the acute tests is the most relevant because ship discharges are not stationary sources and acute tests show immediate effects. ADEC will continue to analyze for chronic tests for scientific purposes.

[18] *Sun Princess* 2003 conventional pollutant test results had high ammonia of 141 mg/L, relatively high TKN of 120 mg/L and phosphorus 13.4 mg/L. The *Coral Princess'* 2004 conventional pollutant test results had ammonia of 34 mg/L, TKN of 35 mg/L and phosphorus 10.1mg/l.

2. *Spirit of Alaska* graywater may cause adverse acute effects during stationary discharge.
3. *Kennicott* and *Veendam* effluents are not expected to cause either acute or chronic toxicity, even during neap tides.
4. *Spirit of Alaska* graywater and blackwater, *Summit* blackwater and *Coral Princess* blackwater mixed with graywater from accommodations may cause adverse chronic effects on sensitive marine organisms during neap tides
5. ADEC looked at the conventional and priority pollutant results to ascertain what parameter may be causing the echinoderm fertilization problems from the *Summit* and *Spirit of Alaska* discharges. Ammonia and benzoic acid are higher in both vessels' effluent than the other three vessels, which showed no observable effects. Metals are high in discharge from the *Spirit of Alaska* and phenols are high in the *Summit*'s discharge.
6. Data from the 2002, 2003 and 2004 studies indicate that with the exception of small-ship graywater, most effluents do not cause acute effects even during stationary discharge during a neap tide. However, some effluents do show chronic effects on marine organisms during stationary discharge. Two effluents that may cause chronic effects were discharged from large ships with advanced treatment systems[19].

Recommended Additional Studies

1. During the 2005 season, perform a dye study on small-ship discharges that occur above the water line to evaluate modeling assumptions.
2. Retest the *Sun Princess* and the *Coral Princess* to observe whether the adverse 2003 and 2004 results are repeated or may have been affected by bioassay substitution.
3. Perform static non-renewal and static renewal tests on the same effluent to evaluate the differences between the tests and discuss results with the Science Advisory Panel to determine which approach is more appropriate for our monitoring purposes.

[19] The Hamworthy and Lazarus system effluent has shown some chronic effects.

Appendix A Conventional and Priority Pollutant Results taken with the 2004 WET tests.

VESSEL NAME		Coral Princess	Kennicott	Summit	Spirit of Alaska	Spirit of Alaska	Veendam
Sample Date		15-May-04	13-May-04	11-Jun-04	24-May-04	24-May-04	06-Jun-04
Sample type	Units	Mixed	Mixed	BW	BW	GW	Mixed
Ammonia	mg/L	34	0.089	56.6	64	1.17	11
pH		6.8	8.0	7.1	8.3	6.7	7.3
BOD	mg/L	ND	ND	71.9	62.1	202	3.7
COD	mg/L	63	85	176	480	617	154
TSS	mg/L	ND	19.6	ND	151	40.3	ND
Total Cl	mg/L	ND	1.7	ND	ND	ND	ND
fecal coliform	MPN/100 ml	2	17	50	11,000	17,000	ND
free Cl	mg/L	ND	1.1	ND	ND	ND	ND
Oil&Grease	mg/L	5.63	2.33	8.18	30.8	53.5	8.04
TOC	mg/L	15	3.3	53	46	190	16
Alkalinity	mg/L	105	96.3	98.1	307	56.7	216
Total Nitrate as N	mg/L	ND	ND	ND	ND	ND	ND
Total Phosphorus	mg/L	10.1	0.045	0.615	8.36	3.95	5
TKN	mg/L	35	2.42	59.4	65	20.9	15
Settleable solids	mg/L	ND	ND	ND	12	0.1	ND
METALS							
arsenic (TR)	ug/L	ND	5.44	ND	55.8	ND	ND
Arsenic, dissolved	ug/L	ND	5.01	ND	59.2	4.14	ND
chromium (TR)	ug/L	ND	5.13	2.82	4.38	ND	ND
chromium, dissolved	ug/L	ND	2.5	2.92	5.08	ND	ND
copper (TR)	ug/L	27.3	36.6	18.8	46.6	64.2	5.18
copper, dissolved	ug/L	27.4	27.2	3.8	20.5	95.7	4.19
lead (TR)	ug/L	1.02	ND	ND	9.38	ND	ND
lead, dissolved	ug/L	ND	ND	ND	5.91	2.48	ND
nickel (TR)	ug/L	10.7	9.39	1.42	7.1	4.18	19.2
nickel, dissolved	ug/L	11.1	9.51	1.03	7.6	4.07	18.5
selenium (TR)	ug/L	ND	168	5.66	132	ND	ND
selenium, dissolved	ug/L	ND	170	3.35	132	ND	ND
zinc (TR)	ug/L	82.2	77	168	4950	384	111
zinc, dissolved	ug/L	153	85.2	142	1640	401	140
BNAs							
4-nitrophenol	ug/L	21	ND	ND	ND	ND	ND
Phenol	ug/L	40	ND	630	ND	ND	ND
3&4 Methylphenol	ug/L	ND	ND	860	24	8.1	ND
di-n-butylphthalate	ug/L	1.9	ND	ND	2.6	15	ND
bis(2-ethylhexyl)phthalate	ug/L	ND	ND	ND	18	22	ND
diethylphthalate	ug/L	ND	ND	ND	ND	16	ND
Benzoic Acid	ug/L	ND	ND	360	310	380	ND
VOCs							
2-butanone	ug/L	ND	ND	87	0.71	1.5	ND
Chloroform	ug/L	ND	ND	2.4	ND	19	ND
Tetrachloroethane	ug/L	ND	ND	ND	ND	ND	11

ND is non-detection or the value is below the minimum method detection limit.