Alaska Department of Environmental Conservation

Commercial Passenger Vessel Environmental Compliance Program

2003 Whole Effluent Toxicity Test Results for Commercial Passenger Vessels in Alaska

Summary

The Alaska Department of Environmental Conservation (ADEC) conducted whole effluent toxicity (WET) testing on commercial passenger vessels in 2002[1] and again in 2003. In 2002, ADEC conducted this testing on the *Dawn Princess, Mercury, Volendam*, *Kennicott*, and *Yorktown Clipper*. The WET tests performed in 2002, indicated that acute or chronic toxic effects on marine organisms are not expected at the high dilutions that occur when vessels are underway.[2]

From the period of June through September 2003, ADEC conducted WET testing on the following vessels: *Norwegian Wind, Sun Princess, Carnival Spirit, Ryndam, Spirit of Oceanus*, and *Spirit of Columbia*. The large vessels (*Norwegian Wind, Sun Princess, Carnival Spirit, Ryndam)* have U.S. Coast Guard certification to discharge wastewater any time anywhere including in port. The small ships (*Spirit of Oceanus*[3] and *Spirit of Columbia*) are also allowed to discharge in port.[4] However the *Spirit of Oceanus* only discharges when underway.

ADEC designed the 2003 WET test to determine if there are any negative effects to the marine environment during stationary discharges where dilution rates will be low. ADEC modeled the discharges during the worst case scenario, a neap tide, where tidal currents are the minimum for the month.

The 2003 results indicate that the *Spirit of Columbia* graywater may cause acute or chronic effects while discharging in port during low tidal flux because of the limited dilution. The 2003 results also indicate that **most ships' wastewater effluent will not cause toxicity, even during periods of minimal tidal flux**.

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[1] See 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)" http://www.state.ak.us/dec/press/cruise/documents/wetreport.htm

[2] 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 http://www.state.ak.us/dec/press/cruise/documents/impact/dilutionwastewater.htm

[3] *Spirit of Oceanus* is a small ship with almost 250 passengers. This vessel is large enough to have wastewater holding capacity. *Spirit of Oceanus* discharges outside 1 mile going a minimum of 6 knots.

[4] The discharge standards and conditions do not apply to small cruise ships until January 1, 2004.

Methodology

Seven effluent samples from six cruise ships operating in Alaska waters were taken in June through September 2003 and analyzed for whole effluent toxicity (WET). The sampling events were arranged and scheduled in advance. The effluents covered a range of sources and treatment systems and came from both large and small cruise ships.

The sampling, transporting, and testing followed standard EPA methods and met all test acceptability criteria. A different bioassay was substituted for the bivalve bioassay for the *Sun Princess*. The substitution was necessary because the bivalves had difficulty spawning this season due to higher than normal summer water temperatures. This bioassay was not part of the Quality Control Plan but the lab felt that ADEC would receive similar results. The lab was not able to perform the echinoderm fertilization chronic tests on the *Spirit* sample because it arrived late in the season (September) and the organisms were not available.

The other tests fulfilled the requirements of the quality assurance (QA) plan. The laboratory was certified to conduct WET tests by the Washington Department of Ecology. The tests were run on a dilution series of six different concentrations of effluent. Since most of these ships are discharging in-port, ADEC used EPA's recommended WET dilution series (100%, 50%, 25%, 12.5%, 6.25%, 3.125%) as the basis for this test.[5] ADEC did not expect to see any effects at 100% dilution so we used the following series (50%, 25%, 12.5%, 6.25%, 3.125%, 1.5%). This series represented concentrations that are attained in receiving waters with dilution factors of 2, 4, 8, 16, 32, and 66.7.

The test species were selected because of their sensitivity and well established testing protocols. Each effluent was tested using two different species for acute tests (where lethality was the effect measured) and two different species for chronic tests (where sub-lethal effects were measured). Conventional and priority pollutants were taken simultaneously and are available in the Appendix A.

Modeling

ADEC modeled dilution factors using the PLUMES model in three popular cruise ship ports: Juneau; Skagway; and Ketchikan during a slack tide of a neap tide[6] with no wind effects such as waves or current shear, which may also enhance mixing. The most conservative results occurred in Skagway. ADEC used the Skagway dilution factors in conjunction with the WET testing results to determine if any acute or chronic toxic effects occur after dilution.

The PLUMES model was designed for discharges that occur under the waterline. This model calculates initial dilution as well as far field dilution.[7] *Spirit* and *Spirit of Columbia* discharge wastewater above the waterline. After inputting these discharges into the PLUMES model, ADEC calculated a 1:1 dilution. ADEC acknowledged that some dilution must occur as the water is entering the ambient water body but PLUMES, by design, could not calculate it. In order to use the PLUMES

[5] http://www.epa.gov/waterscience/WET/guide/wetguide.pdf page 5-1
[6] Period of minimal tidal flux.

[7] 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/

model, ADEC treated ships that discharge above the waterline as if they were discharging 2 inches (5 centimeters) below the waterline.

Ports and harbors have minimum wave action by design, therefore reducing far field dilution effects. Stationary vessels have a boundary layer around the hull that decreases the effluent'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 sea water. The effluent's temperature and salinity affects its density. The water's density affects its ability to disperse.

What do the test results say?

The results of the WET test bioassays and a comparison to modeled dilution factors during a very conservative neap tide scenario can be found in Table 1. For ease of understanding, we focused on comparisons to no observable effects concentrations (NOEC). 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 1:
Whole Effluent Toxicity Test Results & Dilution Factor during Neap Tide
No Observed Effect Concentration (NOEC) in % Effluent

Vessel	Treatment System	Dilution Factor that occurs during Neap Tide Based on PLUMES	Mysid Acute NOEC	Topsmelt Acute NOEC	Bivalve Larvae NOEC		Echinoderm Fertilization NOEC
					Normality[8]	Survival	
Spirit of Columbia Blackwater	Macerator/ Chlorinator	50[9]	>50% (>1:2)	50% (1:2)	50% (>1:2)	50% (>1:2)	25%. (1:4)
Spirit of Columbia Graywater	Untreated	2.5[10]	12.5% (1:8)	25% (1:4)	6.25% (1:16)	25% (1:4)	<1.5% (unknown)
Spirit of Oceanus Mixed Effluent	BW Biological GW untreated	8	25% (1:4)	12.5% (1:8)	<1.5% (unknown)	12.5% (1:8)	<1.5% (unknown)
Norwegian Wind Mixed Effluent	Scanship Bioreactor/ultra -filtration	24	>50% (>1:2)	12.5% (1:8)	6.25% (1:16)	50% (1:2)	25% (1:4)
Ryndam Mixed Effluent	Aerated Membrane (Ultrafiltration)	60	>50% (>1:2)	50% (1:2)	12.5% (1:8)	50% (1:2)	50% (>1:2)
Sun Princess Mixed Effluent	Hamworthy Bioreactor and Ultrafiltration	15	12.5% (1:8)	12.5% (1:8)	<1.5%[11] (unknown)	50% (1:2)	<1.5% (unknown)
Spirit Graywater	Reverse Osmosis	5	>50% (>1:2)	50% (1:2)	25% (1:4)	50% 1:2	Unable to run[12]

What do the test results mean?

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. Since this is only one test, it is not statistically significant but it gives some indication of how different treatment systems are performing. A description of the WET process is provided in Appendix B.

There are two ways to perform the WET test: static non-renewal and static renewal. In a static non-renewal test, the test organisms are exposed to a single portion of the test solution for the duration of

[8] Normality is the normal development of the bivalve larvae.
[9] *Spirit of Columbia's* blackwater is discharged from a pump under the waterline, which increases dilution.
[10] *Spirit of Columbia's* graywater is discharged directly from drains by means of gravity, which decreases dilution.
[11] S. propuratus gametes is not a bivalve but was substituted because the mussels and oysters would not spawn due to elevated summer temperatures.
[12] The organisms were not available when the sample arrived in September.

the test. In a static renewal test, the test organisms are exposed to fresh changes of the test water every day for the duration of the test.

The 2002 and 2003 tests were performed using static renewal testing. This static renewal testing is more conservative because the organisms are exposed to the effluent at the same strength for a longer time period.

Spirit of Columbia
The *Spirit of Columbia* has two separate waste water discharges. A WET test was run on each stream.

Blackwater
The *Spirit of Columbia's* dilution factor in a worst case scenario is enough to protect sensitive marine organisms from acute and chronic effects. Based upon the WET testing and modeling results, ADEC does not expect *Spirit of Columbia* blackwater discharge to cause acute or chronic toxic effects to marine organisms.

The *Spirit of Columbia's* blackwater showed no observable effects, even though the chlorine results were 50 ppm. ADEC checked with the lab to confirm the validity of the chlorine sample. The chlorine result taken at the WET testing lab was 0.03 ppm. The chlorine may have been consumed during the trip to Seattle. The 2002 small ship blackwater results also showed no observable affects at any dilution series.[13] The 2003 blackwater sample has a conductivity of 35,000. This indicates that a majority of the waste water is made up of saltwater or ambient seawater.

Graywater
The graywater is discharged above the waterline with limited dilution. The worst case scenario dilution factor of the *Spirit of Columbia* is not enough to protect sensitive marine organisms from acute and chronic toxic effects. *Spirit of Columbia* graywater discharge may cause acute and chronic toxicity to marine organisms during neap tide events in Skagway.

Spirit of Oceanus

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 during stationary discharges. There would be no acute toxicity at this minimal dilution. The tests show that the effluent exhibits some chronic toxicity at this dilution rate. However, the vessel only discharges while underway when the effluent is expected to be diluted at a rate of approximately 100,000.[14] Therefore no toxicity to marine organisms is expected to result under normal operating procedures.

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[13] Science Advisory Panel for Alaska Department of Environmental Conservation
Commercial Passenger Vessel Environmental Compliance Program 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

Norwegian Wind

Norwegian Wind'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 the chronic and acute WET tests. Based upon the WET testing results and modeling, ADEC does not expect the *Norwegian Wind* end of pipe discharge to cause acute or chronic toxic effects to marine organisms.

Ryndam

Ryndam'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 the chronic and acute WET test. Based upon the WET testing results and modeling, ADEC does not expect the *Ryndam* end of pipe discharge to cause acute or chronic toxic effects to marine organisms.

Sun Princess

Sun Princess' dilution factor in a worst case scenario exceeds the dilution required to produce no observable acute effects on both the acute tests and the survival of the bivalve chronic test. ADEC does not expect *Sun Princess* to cause any acute toxicity to marine organisms.

However, the modeled dilution at low tidal flow conditions is not large enough to protect from negative chronic effects on echinoderm fertilization and the normal development of the bivalve larvae. The bivalve larvae were substituted with *S. purpuratus* gametes. Although this was a deviation from the project's Quality Assurance Plan, the lab thought that the test would yield equivalent results.

This sample arrived at the lab at a temperature of 0 Celsius and had with light ice formation. It was determined this would not affect the test and the test was run. In summary, there are some quality assurance questions on the WET testing chronic analysis for this sample. ADEC presents the results but will probably retest this ship during the 2004 season.

Spirit

Spirit discharges wastewater above the waterline so it has a small dilution factor. Even this small factor, however, is enough to not cause acute or chronic effects on the sensitive marine organisms. Based upon the WET testing results and modeling, ADEC does not expect *Spirit's* discharge to cause acute or chronic effects to marine organisms.

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[14] 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^3sec^{-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^3sec^{-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

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.
2. *Spirit of Columbia* blackwater, *Norwegian Wind, Ryndam,* and *Spirit* effluent are not expected to cause either acute or chronic toxicity, even during neap tides.
3. *Spirit of Columbia* graywater and *Sun Princess* mixed effluent may cause adverse chronic effects on sensitive marine organisms during periods of low tidal exchange. *Spirit of Oceanus* may cause adverse chronic effects during stationary discharge. However, it is standard operating procedure for this vessel to discharge while underway.
4. Only the untreated graywater from the small ship (*Spirit of Columbia)* is expected to exhibit acute toxicity during neap tides.

Recommended Additional Studies

1. Perform a dye study on small ship discharges that occur above the water line to evaluate assumptions made during modeling.
2. Retest the *Sun Princess* to see if the 2003 results repeat themselves or determine if they were affected by ice and bioassay substitution.
3. Perform static non-renewal tests where the test organisms are exposed to a single portion of the test solution for the duration of the test. In the static renewal tests that have been conducted the past two years, the test organisms are exposed to fresh changes of the test water every day for the duration of the test.

Appendix A

Conventional and Priority Pollutant Results taken in conjunction with the WET tests.

Sample Name	Units	Spirit of Columbia BW	Spirit of Columbia GW	Spirit of Oceanus Combined	Norwegian Wind TWW	Ryndam Combined	Sun Princess Combined	Spirit
CONVENTIALS								
Ammonia, total (as N)	mg/L	0.93	0.86	75.9	49	10.6	141	2.3
pH		8.1	7.5	7	6.95	7.7	7.3	7.04
BOD5	mg/L	ND	134	420	8.12	3.4	20	23.7
COD	mg/L	836	126	828	71	52	162	67
TSS	mg/L	28.9	48.5	91.8	11.2	ND	ND	ND
total chlorine residual (WET lab result)	mg/L	**50 (0.03)**	**ND (0.17)**	**ND**	**ND**	**ND**	**0.62**	**ND**
free chlorine residual (Wet lab result)	mg/L	**50**	**ND**	**ND**	**ND**	**ND**	**0.62**	**ND**
Fecal coliform	MPN/ 100 ml	1,400	16,000	16,000,000	ND	ND	ND	23
Conductivity		35,000	111	2,010	937	823	2,920	131
hexane-extractable material	mg/L	ND	ND	ND	ND	ND	ND	ND
total organic carbon	mg/L	3.67	7.95	Missing	15.4	14.5	44.5	12.7
Alkalinity	mg/L	85.1	25	312	78.3	308	539	32.7
total nitrate and nitrite as N	mg/L	ND	ND	ND	ND	ND	ND	ND
total phosphorus	mg/L	0.42	1.2	6.6	0.16	2.1	13.4	0.3
total kjeldahl nitrogen	mg/L	2.3	3.5	79	35	12	120	6
total settable solids	mg/L	ND	ND	ND	ND	ND	ND	ND

Sample Name	Units	Spirit of Columbia BW	Spirit of Columbia GW	Spirit of Oceanus Combined	Norwegian Wind TWW	Ryndam Combined	Sun Princess Combined	Spirit
Metals[15]								
antimony (TR)	ug/L	**1.56**	**1.39**	1.42	0.15	0.198	**0.127**	0.147
Antimony, dissolved	ug/L	**2.55**	**1.76**	1.23	0.107	0.159	**0.229**	ND
arsenic (TR)	ug/L	66.3	**1.13**	**3.39**	1.21	**0.704**	3.48	0.232
Arsenic, dissolved	ug/L	56.1	**1.32**	**4.18**	1.17	**0.795**	3.28	ND
beryllium (TR)	ug/L	ND	ND	ND	0.0389	ND	0.022	ND
Beryllium, dissolved	ug/L	ND	ND	ND	ND	ND	ND	ND
cadmium (TR)	ug/L	ND	0.303	ND	ND	ND	ND	ND
Cadmium, dissolved	ug/L	ND	0.0699	ND	ND	ND	ND	ND
chromium (TR)	ug/L	**3.52**	**2.1**	3.49	0.947	**0.859**	**4.97**	0.33
Chromium, dissolved	ug/L	**3.56**	**2.73**	1.29	0.449	**3.62**	**6.92**	**0.392**
copper (TR)	ug/L	**24.5**	**118**	196	4.54	7.66	21.3	4.69
Copper, dissolved	ug/L	**25.1**	**148**	20.2	3.41	7.21	18.9	2.59
lead (TR)	ug/L	2.93	**5.73**	3.97	0.32	**0.126**	0.367	0.468
lead, dissolved	ug/L	1.21	**6.53**	1.69	0.321	**0.204**	0.334	0.129
nickel (TR)	ug/L	**14.7**	**9.51**	6.51	**39.2**	**22**	8.16	3.94
nickel, dissolved	ug/L	**24.3**	**11**	6.17	**39.7**	**22.4**	8.05	3.07
selenium (TR)	ug/L	178	**3.66**	8.23	1.11	0.715	5.06	ND
selenium, dissolved	ug/L	171	**4.12**	ND	1.05	0.661	3.42	ND
silver TR	ug/L	**ND**	ND	0.925	ND	0.967	ND	0.141
silver, dissolved	ug/L	**1.15**	ND	ND	ND	ND	ND	ND
thallium (TR)	ug/L	**ND**	0.0939	ND	ND	ND	ND	ND
Thallium, dissolved	ug/L	**0.612**	0.0699	ND	ND	ND	ND	ND
zinc (TR)	ug/L	81.2	**617**	311	**66.6**	**116**	111	54.2
zinc, dissolved	ug/L	74.4	**715**	278	**106**	**124**	103	47

[15] Some of the dissolved metals are higher than the Total Recoverable. Since a dissolved metal is a component of the total recoverable metal this should NOT be the case. The samples are taken in two separate containers at slightly different times. In addition the filter used in the dissolved metals test may increase the dissolved metal result. D. Wetzel email 11/18/03.

Sample_Date		09-Jul-03	09-Jun-03	12-Jun-03	18-Jun	20-Jun-03	16-Jun-03	12-Sep-03
Sample_Name	Units	Spirit of Columbia Blackwater	Spirit of Columbia GW	Spirit of Oceanus Combined	Norwegian Wind TWW	Ryndam combined	Sun Princess Combined	Carnival Spirit
VOCs								
acetone	ug/L	3.9	6.1	70	52	200	3.9	41
chloroform	ug/L	ND	7.9	17	1.7	1.4	4.1	6.3
bromoform	ug/L	3	ND	2.7	ND	ND	ND	ND
dibromochloromethane	ug/L	1.5	0.95	5.2	ND	ND	ND	ND
bromodichloromethane	ug/L	0.66	1.3	5.4	ND	ND	ND	ND
methylene chlorine	ug/L	0.59	0.92	1.5	ND	1	ND	ND
4-methyl-2-pentanone	ug/L	ND	ND	ND	8.2	ND	ND	ND
dibromomethane	ug/L	ND	ND	2.1	1.4	ND	ND	ND
chlorobenzene	ug/L	ND	ND	ND	ND	ND	ND	ND
bromomethane	ug/L	ND	ND	ND	ND	ND	ND	ND
toluene	ug/L	ND	ND	1.9	0.59	ND	ND	1.6
BNA								
Benzyl Alcohol	ug/L	Missing	Missing	Missing	Missing	Missing	Missing	300
bis(2-ethylhexyl)phthalate	ug/L	ND	ND	8.2	1.2	ND	ND	ND
diethylphthalate	ug/L	ND	ND	7.8	5.8	ND	ND	19
di--n-butylphthalate	ug/L	ND	ND	2.1	1.7	ND	ND	2.2
hexachlorobutadiene	ug/L	ND	ND	ND	ND	ND	13	ND
n-nitroso-di-n-proplyamine	ug/L	ND	ND	ND	ND	ND	14	ND
phenol	ug/L	ND	ND	29	ND	ND	ND	ND

Appendix B

Whole Effluent Toxicity (WET) Testing
Theory, Procedures, and Process

Whole Effluent Toxicity (WET) testing is an alternative to directly analyzing environmental samples for individual constituents. In WET testing, impact of a discharge stream on the environment can be evaluated in terms of its short (acute) or long-term (chronic) lethal or reproductive effects on indigenous animal species. Test organisms are exposed to various dilutions. Conditions of exposure can be varied based on the desired type of response. 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 fresh changes of the test water every day for the duration of the test. In a flow through test, the test organisms are continuously exposed to fresh batches, or mixes of test solution. Both the acute and the chronic tests were static. 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. An example of how the LC is expressed would be a "48-hr LC_{50}." This is the concentration of the test sample that resulted in death of 50% of the organisms after a 48-hour exposure. A dose response expresses the response of the organism to a toxicant based upon body weight or dilution. The curve plots percent response verses log dose.[17] Sub-lethal effect concentrations (EC) can be similarly described.

This WET testing investigation examined the toxicity of six effluent samples from six commercial cruise ships using marine organisms. Mysid shrimp (*Mysidopsis bahia)* and Topsmelt (*Atherinops affinis)* were selected as the test organisms for the acute testing. Survival was evaluated after a 48-hour exposure period to the Mysid shrimp and a 96-hour exposure period to the Topsmelt. The bivalve *Mytilus galloprovincialis* and the echinoderm *Strongylocentrotus purpuratus* were used as the test organisms for the chronic tests. Test concentrations examined were 50%, 25% 12.5%, 6.25%, 3.125%, 1.5% of the effluent.

EPA has a method for calculating a concentration from an LC_{50} that represents "virtually no mortality." However, the reported acute NOECs are sufficient for our evaluation. The acute NOECs varied from 50% to 1.5% effluent. Note that a 1.5% effluent concentration is attained after a dilution factor of only 66.7. Discharges from moving cruise ships attain much greater dilutions and acute whole effluent toxicity is not a concern for discharges when moving. There may be concerns during stationary discharges.

The chronic bioassay results have NOECs varying from 50% to <1.5% effluent. Alaska has a water quality standard of 1 chronic toxic unit (TU_c). The chronic toxic units for a discharge may be determined by dividing 100 by the NOEC. Consequently, the chronic toxic units observed in the above effluents varied from 2 to >66.7. Any dilution at > 66.7 is labeled as unknown. Following Alaska and EPA's approach, dilution is considered in determining where the 1 TU_c standard is to be

[17] Smith, Roy-Keith, Handbook of Environmental Analysis, Fourth Edition, Genium Publishing Corporation, 1999.

applied. The chronic toxic units actually are the same as the dilution factor needed to meet the 1 TU_c standard.