# Alaska Department of Environmental Conservation
# Commercial Passenger Vessel Environmental Compliance Program

## Discussion of 2005 Whole Effluent Toxicity (WET) Test Results from Commercial Passenger Vessels Discharging Wastewater in Alaska


### Summary

The Alaska Department of Environmental Conservation (ADEC) conducted whole effluent toxicity (WET) testing annually on selected vessels from 2002 through 2005. The ADEC selected vessels based on the treatment systems installed on board. In WET testing, impact of a discharge to the environment can be evaluated in terms of its short (acute) or long-term (chronic) effects[1] on indigenous animal species. Test organisms are exposed to various concentrations of sampled vessel wastewater 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 at the high dilutions that occur when vessels are underway.[3]

ADEC designed the 2003 WET test to determine if there are any negative effects to the marine environment from 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 show that there were no chronic or acute effects on marine organisms for two large ships with advanced treatment systems (*Norwegian Wind* and *Ryndam*) and one small ship (*Spirit of Columbia'*s blackwater) with a traditional MSD. One small ship's (*Spirit of Columbia*) graywater results showed acute and chronic toxicity during periods of lowest dilution. One large ship with advance treatment system (*Sun Princess*) showed chronic toxicity during in port discharges with low dilution. Another 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.

ADEC designed the 2004 WET test similar to the 2003 tests to determine if there are any negative effects during low dilution discharges. The 2004 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 tides. *Spirit of Alaska* blackwater and *Summit* blackwater may cause chronic effects. *Coral Princess's* advanced treated mixed


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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 "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**

accommodations graywater and blackwater may cause adverse *chronic* effects on bivalve larvae development during periods of low tidal exchange. *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 from both large and small commercial passenger vessels discharging into Alaska water.

| Type (treatment) | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|
| Large Ship (Hamworthy) | *Dawn Princess* | *Sun Princess* | *Coral Princess* | *Sun Princess* |
| Large Ship (Scanship) | | *Norwegian Wind* | | *Norwegian Dream* |
| | | | | *Serenade of the Seas* |
| Large Ship (other) | | | *Summit* | |
| Large Ship (Zenon) | *Volendam* | *Ryndam* | *Veendam* | *Ryndam* |
| Large Ship (Rochem) | *Mercury* | *Carnival Spirit* | | |
| Small Ship (traditional) | *Kennicott* | *Spirit of Oceanus* | *Kennicott* | *Malaspina* |
| | *Yorktown Clipper* | *Spirit of Columbia* | *Spirit of Alaska* | *Sea Lion* |

## Methodology

An ADEC term contractor, Shannon & Wilson (S&W) took effluent samples from three commercial passenger vessels. S&W scheduled the sampling events in advance with the vessel operators. ADEC took effluent samples from 1 large vessel, and 1 state ferry. The remaining small vessel sample was taken by vessel personnel. The sampling events took place during May and June 2005. The samples were analyzed within 36 hours of sampling by Nautilus Environmental located in Tacoma, WA and San Diego, CA. Conventional and priority pollutants were taken simultaneously and are available in Appendix A. Both laboratories are certified to conduct WET tests by the State of Washington's Department of Ecology.

The laboratory analyzed the samples for acute and chronic effects using ADEC selected test organisms. ADEC, with the input of the Science Advisory Panel selected test organisms for the acute testing. The test species were selected because of their sensitivity and well established testing protocols. The acute testing included the organisms Mysid shrimp (*Mysidopsis bahia)* and Topsmelt (*Atherinops affinis)*. Survival was evaluated after a 48-hour effluent exposure period to the Mysid shrimp and a 96-hour effluent exposure period to the Topsmelt.

Chronic effects were determined by evaluating several different organisms. Chronic tests evaluated the larval development of bay mussels *(Mytilus edulis, or Mytilus galloprovincialis),* and the germination of giant kelp spores (*Macrocystis pyrifera)* after a 48 hour exposure. An additional chronic test included the fertilization of the echinoderm (*Strongylocentrotus purpuratus)* after a 40 minute exposure.

The sampling, transporting, and testing met requirements of the project's Quality Assurance Quality Control (QAQC) plan, which followed standard EPA methods and met all test acceptability criteria except the following issues. A different bioassay (oysters) was substituted for the ADEC selected bivalve bioassay (mussel) for the *Malaspina* and *Norwegian Dream* due to natural spawning cycles. Similarly, a substitute bioassay (sand dollar) was used instead of the selected echinoderm (urchin) for the vessel Ryndam. However, there were quality assurance issues with the sand dollar fertilization test and the results are not reported. Oysters and sand dollars were not part of the project's QAQC plan but the lab felt that ADEC would receive similar results.

The tests were run on a dilution series of six different concentrations of effluent. Since most of these ships are discharging in-port, ADEC requested the following WET dilution series (50%, 25%, 12.5%, 6.25%, 3.125% and 1.56%, control) as the basis for this test. This series represented concentrations that are attained in receiving waters with dilution factors of 2, 4, 8, 16, 32, and 64.

The WET test method can vary the conditions of exposure based on the desired type of response. In a static 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. ADEC required the lab to perform acute WET tests using static renewal, and chronic tests using the static method.

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.

## Modeling

In 2003, ADEC modeled individual ship's dilution factors using the PLUMES model in Skagway, Juneau and Ketchikan during a slack tide of a neap tide with no wind effects such as waves or current shear, which may also enhance mixing. The most conservative results occurred in Skagway. Therefore, ADEC used Skagway again in 2004 and 2005 as the conservative receiving waters. ADEC compares individual ship's dilution factors with the ship's WET testing results to determine if any toxic effects occur during periods of minimal tidal flux.

The PLUMES model was designed for discharges that occur under the waterline. This model calculates initial dilution as well as far field dilution.[4] *Sea Lion* discharges graywater above the waterline. After inputting these discharges into the PLUMES model, the calculated dilution ratio was one, which means that no dilution occurred. ADEC acknowledged that some dilution must occur as the water is entering the ambient water body but PLUMES, by design, could not calculate

[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/

it because the discharge occurred above the waterline. In order to use the PLUMES model, 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 treated above waterline discharges as 6 inches below the water line.

Some of the individual ships' dilution factors are small. Ports and harbors have minimum wave action and by design reduce 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 marine water. The effluent's temperature and salinity affect its density and how it disperses with the ambient water.

## What do the test results say?

Table 1 shows the results of the 2005 WET test bioassays. For ease of understanding, ADEC focused on the no observable effects concentrations (NOEC). This is the level ADEC used to analyze the results from 2002 through 2004.

**Table 1: 2005 WET Results showing No Observed Effect Concentration (NOEC) in Percent % Effluent**

| Vessel | Effluent Type | Treatment System | Mysid Acute NOEC | Topsmelt Acute NOEC | Bivalve Larvae NOEC | | Kelp Spore NOEC | | Echinoderm Fertilization NOEC |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Normality | Survival | Germination | Germination Tube Length | |
| *Sea Lion* | Blackwater | Macerator/ Chlorinator | 50% | 50% | 25% | 50% | 12.5% | 25% | 3.125 |
| *Sea Lion* | Graywater | Chlorine Injection | 12.5% | 25% | 6.25% | 50% | 3.12% | 3.12% | 3.125% |
| *Malaspina* | Mixed Blackwater & Graywater | Macerator/ Chlorinator | 12.5% | 12.5% | 3.125% | 3.125% | 1.56% | <1.56% | <1.56% |
| *Ryndam* | Mixed Blackwater & Graywater | Zenon | 50% | 50% | Can not use; QA issues | 50% | 50% | 50% | Can not use; QA issues |
| *Norwegian Dream* | Mixed Blackwater & Graywater | Scanship | 50% | 25% | 1.56% | 12.5% | 50% | 12.5% | 25% |
| *Serenade of the Seas* | Mixed Blackwater & Graywater | Scanship | 50% | 25% | 12.5% | 12.5% | 50% | 25% | Can not use data; QA issues |
| *Sun Princess* | Mixed Blackwater & Accommodations Graywater | Hamworthy | 25% | 12.5% | 3.125% | 50% | 50% | 50% | 25% |

Table 2 shows the 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 has highlighted the tests that may cause effects.

**Table 2: 2005 Vessel Dilution factor compared with the dilution factor needed to have No Observed Effect Concentration (NOEC)**

| Vessel | Effluent Type | Dilution Factor | Mysid Acute NOEC | Topsmelt Acute NOEC | Bivalve Larvae NOEC | | Kelp Spore NOEC | | Echinoderm Fertilization NOEC |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Normality | Survival | Germination | Germination Tube Length | |
| *Sea Lion* | Blackwater | 60 | 2 | 2 | 4 | 2 | 8 | 4 | 32 |
| *Sea Lion* | Graywater | 2.5 | 8 | 4 | 16 | 2 | 32 | 32 | 32 |
| *Malaspina* | Mixed BW & GW | ? | 8 | 8 | 32 | 32 | 64 | 64 | 64 |
| *Ryndam* Mixed Effluent | Mixed BW & GW | 60 | 2 | 2 | Unknown | 2 | 2 | 2 | Unknown |
| *Norwegian Dream* Mixed Effluent | Mixed BW & GW | ? | 2 | 4 | 64 | 8 | 2 | 8 | 4 |
| *Serenade of the Seas* Mixed Effluent | Mixed BW & GW | ? | 2 | 4 | 8 | 8 | 2 | 4 | Unknown |
| *Sun Princess* Mixed Effluent | Mixed BW & GW | 15 | 4 | 8 | 32 | 2 | 2 | 2 | 4 |

## What do the test results mean?

### ***Sea Lion***

The *Sea Lion* has separate waste black water and graywater discharges. A WET test was run on each stream.

*Blackwater*
The *Sea Lion'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 acute and chronic WET tests. Based upon the WET testing results and modeling, ADEC does not expect the *Sea Lion's* blackwater to cause acute or chronic toxic effects to marine organisms.

*Graywater*
The worst case scenario dilution factor for graywater from the *Sea Lion* is not enough to protect marine organisms from acute and chronic toxic effects. Most of the *Sea Lion's* gray water from the galley and accommodations is discharged by gravity above the waterline, except for the sampled graywater. The sampled graywater was from a holding tank that was pumped overboard at 45 gallons per minute. The sample was taken from the ship while the ship was underway. Using the PLUMES model, ADEC expects a dilution factor of 2.5 when discharging into ambient water at neap tide. *Sea Lion* graywater discharge may cause acute and chronic toxicity to marine organisms during neap tide events in Skagway.

### ***Malaspina***

The Malaspina's effluent could not be modeled in this study due to lack of input information. However, the WET test results clearly show that even if the effluent is diluted there will be deleterious and toxic effects on marine organisms. The chronic effects are the greatest for any vessel tested in 2005. If the dilution is assumed to be modest there will be acute effects as well during neap tide events in Skagway.

### ***Ryndam***

*Ryndam's* dilution factor in a worst case scenario exceeds the dilution required to produce no observable effects on the marine organisms tested during both of the acute WET tests. The *Ryndam* was included in the 2003 WET test study and showed similar results. The ADEC chose the *Ryndam* (Zenon) a second time to compare results and because of the 2002 and 2004 results for the *Volendam* and *Veendam* (both using Zenon systems). All of the WET studies conducted by ADEC on the Zenon systems have shown that the dilution factor exceeds the dilution required to produce no observable effects for chronic WET testing. 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.

***Norwegian Dream***

The mixed effluent from the *Norwegian Dream* was not modeled in this study due to a lack of input data. The WET test for bivalve development shows that there will clearly be chronic effects even if dilution is assumed for this vessel. Without additional information it is not possible to assess if there will be acute toxic effects from discharging in port during neap tides in Skagway.

**Serenade of the Seas**

The mixed effluent from the *Serenade of the Seas* was not modeled in this study due to a lack of input information. The results of WET testing for this ship show that it is unlikely that the effluent would generally have acute or chronic toxic effects to marine organisms under the conditions expected in port in Skagway. Since the Serenade of the Seas is a large ship, it is possible that discharge would show at least a moderate dilution factor.

***Sun Princess***

*Sun Princess'* dilution factor in a worst case scenario is higher than the dilution required to produce no observable acute effects on acute tests. However, the modeled dilution at low tidal flow conditions is not large enough to protect from chronic effects on the normal development of the bivalve larvae. The 2003[5] results for the *Sun Princess* also showed similar effects on the normal development of bivalve larvae.

In addition, the chronic tests from 2004 show that the *Coral Princess,* which also has a Hamworthy treatment system, showed similar effects on the normal development of bivalve larvae.

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

## Conclusions

1. Many of the tested wastewater effluent are not expected to cause acute toxicity to marine organisms, even at the worst case scenario dilutions that occur during neap tides. The acute tests are the most relevant because ship discharges are not stationary sources. Acute tests show immediate effects.
2. *Sea Lion* graywater and the mixed effluent from the *Malaspina* will cause adverse acute effects during stationary discharge. These ships will also cause adverse chronic effects on marine organisms during periods of low tidal exchange.
3. *Ryndam* and *Serenade of the Seas* effluents are not likely to cause either acute or chronic toxicity, even during neap tides.

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[5] *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.

4. The mixed effluents from the *Norwegian Dream* and the *Sun Princess* will cause adverse chronic effects on bivalve larvae during periods of low tidal exchange.
5. The conventional and priority pollutants results listed in Appendix A show that all of the ships tested have Water Quality exceedances for ammonia (chronic) and zinc with the exception of the *Sea Lion* for ammonia. However, from the results table it is clear that the acute toxicity seen in the Malaspina and *Sea Lion* is probably due to copper which is found at levels that exceed Water Quality Standards by a factor of 20. Copper has been shown to be very toxic to a wide range of marine organisms
6. When comparing the data from the 2002, 2003 and 2004 studies, it can be seen that most effluents with the exception of the small ship graywater do not cause acute effects while discharging even while stationary during a NEAP tide. However, we continue to see some effluents that show chronic effects to marine organisms during stationary discharge. Surprisingly two effluents that may cause chronic effects are from large ships with advanced treatment systems[6].

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

## Appendix A Conventional and Priority Pollutant Results taken with the 2005 WET tests.

| Ship | | Norwegian Dream | Malaspina | Ryndam | Sea Lion GW | Sea Lion BW | Serenade of the Seas | Sun Princess |
|---|---|---|---|---|---|---|---|---|
| **Date** | **Units** | **6/29/05** | **6/10/05** | **6/19/05** | **6/18/05** | **6/18/05** | **6/2/05** | **6/13/05** |
| Ammonia as N | mg/l | 33 | 19 | 12 | 1.87 | 2.14 | 32 | 69 |
| pH | pH units | 6.2 | 7.4 | 7.4 | 6.4 | 7.66 | 6.82 | 7.4 |
| BOD | mg/l | 8.52 | 84 | ND | 423 | 72.4 | 22.9 | ND |
| COD | mg/l | 97 | 210 | 55 | 1400 | 470 | 89 | 101 |
| TSS | mg/l | ND | 79.9 | ND | 42.1 | 81.7 | 15 | ND |
| Total Chlorine | mg/l | 0.09 | 18 | 0.06 | ND | 5.4 | ND | 0.08 |
| Free Chlorine | mg/l | 0.07 | 11 | 0.5 | ND | 0.7 | ND | 0.11 |
| Fecal Coliform Bacteria | MPN/100ml | ND | ND | ND | 290 | ND | ND | ND |
| Conductivity | mg/l | 1210 | 33300 | 744 | 570 | 25300 | 1,510 | 3020 |
| Oil& Grease | mg/l | ND | 2.65 | ND | ND | ND | ND | 10.4 |
| TOC | mg/l | 15 | 58 | 13 | 370 | 50 | 33 | 27 |
| Alkalinity | mg/l | 52 | 141 | 56 | 139 | 82.9 | 96.4 | 230 |
| Total Nitrate & Nitrite | mg/l | ND | 4.9 | ND | ND | 0.21 | ND | ND |
| Total Phosphorus | mg/l | 0.55 | 6.4 | 0.35 | 0.64 | 1.2 | 0.35 | 11 |
| TKN | mg/l | 38.1 | 29 | 13.6 | 2.41 | 25.7 | 37.6 | 37.2 |
| Settleable Solids | mg/l | ND | ND | ND | ND | 8 | ND | ND |
| Enterococci | MPN/100ml | n/a | n/a | n/a | n/a | n/a | 2,420 | n/a |
| **METALS** | | | | | | | | |
| Arsenic (TR) | ug/l | ND | 41.4 | ND | ND | n/a | ND | ND |
| Arsenic, dissolved | ug/l | ND | 27.6 | ND | ND | n/a | ND | ND |
| Chromium (TR) | ug/l | ND | ND | ND | 2.82 | n/a | ND | ND |
| Copper (TR) | ug/l | 8.74 | 73.9 | 3.34 | 159 | n/a | 3.45 | 3.45 |
| Copper, dissolved | ug/l | 6.53 | 68 | 3.09 | 58 | n/a | 6.2 | 4.78 |
| Lead (TR) | ug/l | 2.1 | ND | 1.07 | 9.98 | n/a | 3.62 | 1.9 |
| Lead, dissolved | ug/l | 2.61 | ND | ND | 6.24 | n/a | 2.48 | ND |
| Nickel (TR) | ug/l | 39.8 | 17.2 | 13.6 | 5.51 | n/a | 12.2 | 4.33 |
| Nickel, dissolved | ug/l | 33.9 | 15 | 12.7 | 4.62 | n/a | 11.8 | 6.08 |
| Selenium (TR) | ug/l | ND | 144 | ND | ND | n/a | ND | 5.18 |
| Selenium, dissolved | ug/l | ND | 157 | ND | ND | n/a | ND | 6.86 |
| Thallium (TR) | ug/l | 1.1 | 1 | 1.21 | ND | n/a | ND | ND |
| Thallium, dissolved | ug/l | ND | ND | 1.71 | ND | n/a | ND | ND |
| Zinc (TR) | ug/l | 85.7 | 255 | 17 | 217 | n/a | 186 | 38 |
| Zinc, dissolved | ug/l | 127 | 217 | 52.9 | 180 | n/a | 184 | 89.5 |
| **BNA's** | | | | | | | | |
| 2,4-dichlorophenol | ug/l | ND | ND | ND | ND | n/a | 1.1 | ND |
| bis(2-ethylhexyl)phthalate | ug/l | 5 | ND | ND | 11 | n/a | ND | 1.8 |
| diethylphthalate | ug/l | 8 | ND | ND | ND | n/a | 4.1 | 3.1 |
| Benzoic Acid | ug/l | 2.9 | ND | 65 | ND | n/a | 2.9 | 3.6 |
| Benzyl Alcohol | ug/l | 3.6 | 17 | 5 | 45 | n/a | ND | ND |
| **VOC's** | | | | | | | | |
| chloroform | ug/l | 1.3 | 4.2 | 0.45 | 100 | n/a | ND | 4.6 |
| bromoform | ug/l | ND | 230 | ND | ND | n/a | ND | ND |
| dibromochloromethane | ug/l | ND | 58 | ND | ND | n/a | ND | ND |
| bromodichloromethane | ug/l | ND | 11 | ND | 2.2 | n/a | ND | ND |
| toluene | ug/l | ND | ND | ND | ND | n/a | ND | 0.54 |
| Tetrachloroethene | ug/l | ND | ND | ND | 5.4 | n/a | ND | ND |
| Acetone | ug/l | 70 | 25 | ND | 75 | n/a | 86 | 11 |
| O-xylene | ug/l | ND | ND | ND | ND | n/a | ND | 0.2 |

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