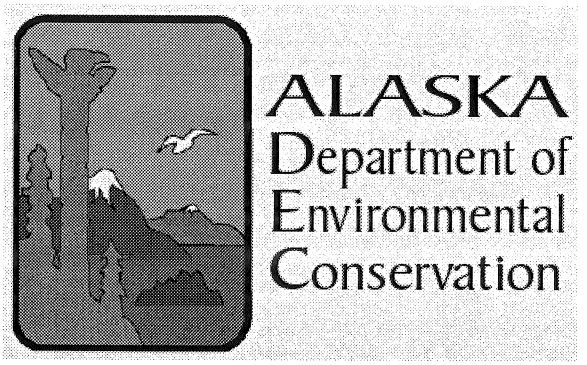


Chlorine Decay Study of Wastewater Discharges to Marine Waters from Stationary Small Commercial Passenger Vessels in Southeast Alaska

Alaska Department of Environmental Conservation

Commercial Passenger Vessel Environmental Compliance Program

November 30, 2006

Project Study Report
Chlorine Decay Study of Wastewater Discharges to Marine Waters from Stationary Small Commercial Passenger Vessels in Southeast Alaska

1. Introduction

This study involved conducting laboratory bench-scale evaluations to determine the decay rate of chlorinated wastewater that is discharged to marine surface waters. The study was conducted to provide information to the Commercial Passenger Vessel Environmental Compliance Program of the Alaska Department of Environmental Conservation (ADEC).

Study Objectives

The chlorine decay study was designed to provide a representation of the potential ranges of chlorine decay rates for chlorinated wastewaters from small ship discharges to the surface water of southeast Alaska. Chlorine is used on many small commercial vessels to disinfect wastewaters prior to discharge to receiving waters. This study assumed that blackwater or mixed blackwater-graywater wastes from small ships are macerated and dosed with chlorine, reacted for a period of time, and discharged to the receiving water without de-chlorination (or that de-chlorination system fail). Assuming conservative mixing or dilution with surface waters (dilution is expressed as the ratio of receiving water to wastewater), this study was developed to provide laboratory data on the chlorine decay rate for such a "worst-case" chlorinated waterwater discharge into marine receiving waters. This study provides information to assist ADEC in determining Best Management Practices (BMPs) for small ships to maximize environmental protection of the beneficial uses of the surface waters.

Background

The types of effluents discharged from small ships are categorized as black water (water from toilets) and gray water (wastewater from galleys, laundries, and accommodations). Black water is treated onboard through marine sanitation devices before direct discharge at or below the water surface. Gray water management practices depend on the small ship configuration, and some vessels have limited holding tanks, others have direct discharges, and some combine their gray water with black water prior to discharge. In a 2002 report, *The Impact of Cruise Ship Wastewater Discharge on Alaska Waters,* ADEC developed a detailed summary of the discharges from small commercial passenger vessels.

Attachment 1 provides a summary of the treatment systems and wastewater discharge status for the small commercial passenger vessels operating in Alaskan state waters. ADEC's 2004 report, *Assessment of Cruise Ship and Ferry Wastewater Impacts in Alaska* provides detailed summaries of the wastewater monitoring of large and small commercial vessels operating in Alaska, including details of the various wastewater treatment systems.

Chlorination is one of the disinfection methods used on vessels for blackwater and mixed mixed blackwater/graywater (some vessels use other methods), and some vessels also use effluent de-chlorination stages prior to discharge. However, based on 2005 small ships blackwater sampling by ADEC, total residual chlorine concentrations ranged from 0 to 8.9 mg/L and free residual chlorine ranged from 0 to 8.8 mg/L. These residual chlorine concentrations could pose a risk to receiving water without rapid mixing and degradation.

Wastewater samples exhibit a chlorine demand based on reactions with any reducing agents, ammonia, some inorganic species, and organic material in the wastewater. The chlorine demand is the amount of free chlorine required to reach a specific treatment goal, which may be the breakpoint chlorination point, a free residual value after breakpoint chlorination is achieved, or in the case of this study, the amount of free chlorine required to reach the target combined chlorine residual.

Free chlorine reacts with ammonia very quickly to form chloramines. If there is ammonia in the wastewater sample, then the only way to get free chlorine is to add chlorine until all the ammonia is gone, add more to react with the chloramines, then free chlorine is produced. The point where free chlorine is produced is the chlorination break-point. Figure 1 illustrates a typical breakpoint chlorination process. Presented below are definitions of terms to help understand the chlorination process and breakpoint.

Combined residual chlorine is described as the portion of chlorine injected into water that remains combined with ammonia or nitrogenous compounds after the reaction equilibrium has been reached. 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. Free residual chlorine has a short half-life in marine waters; therefore, it can be difficult to assess the effects of chlorine on aquatic life. However, Alaska's saltwater criteria for total residual chlorine are very low compared to the discharge concentrations of free residual chlorine from vessels: 13 µg/L (acute criterion) and 7.5 µg/L, (chronic criterion). Total chlorine is a measurement of both combined residual and free residual chlorine. Total chlorine analysis is the common way to determine combined chlorine (since combined chlorine can't easily be measured), and the free residual chlorine is subtracted from the total chlorine to determine the combined residual chlorine.

Most small ships, because of their size and configuration, do not have the capacity to hold all of their wastewater while the vessel is docked or at sea, and they discharge as determined by the treatment system capacity and wastewater load. Even with the benefit of dilution, it has been predicted that the discharge of wastewater (blackwater or graywater) from small ships may contain concentrations of chlorine, fecal coliform, copper, and zinc that can potentially exceed Alaska Water Quality Standards. This study was designed and executed to give ADEC information on the rates of reduction (decay) of free residual chlorine and total chlorine in chlorinated blackwater discharges. This study evaluates both blackwater and mixed blackwater/graywater discharges. The results of this study will be used to assist ADEC in developing strategies to reduce the environmental impacts of chlorinated wastewater discharges and in determining Best Management Practices (BMPs) for small ships.

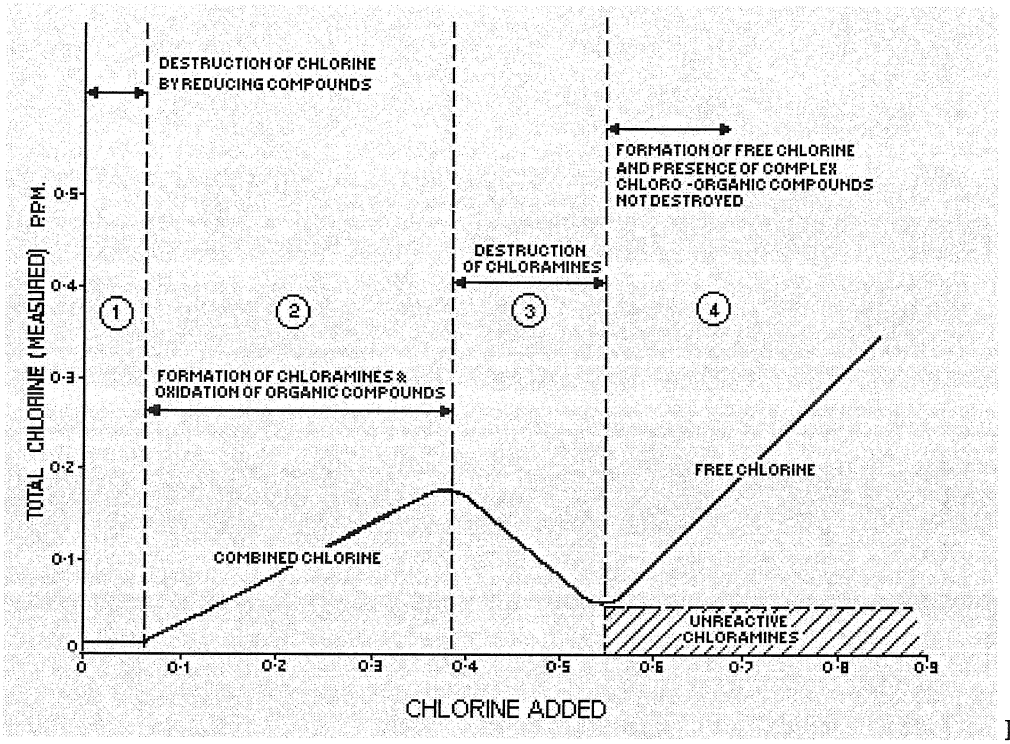


Figure 1

Study Approach

Details of the laboratory bench-scale procedures are presented in the Study Methods section that follows. The laboratory analyses for the bench-scale tests were conducted by CH2M HILL's Applied Sciences Laboratory (ASL) in Corvallis, Oregon.

The project study approach included the use of representative non-disinfected blackwater and blackwater/graywater mix samples. The blackwater sample was collected from the vessel Spirit of 98' on June 15, 2006 following the maceration process on board and without any disinfection. The blackwater/graywater sample was collected from the Alaska State ferry vessel Matanuska on June 14, 2006, and drawn (pumped) directly from the vessel's blackwater/graywater holding tank with out any disinfection. In addition, each wastewater sample was tested for chemical parameters to characterize the sample and compare the sample with historical small vessel wastewater data.

Sodium hypochlorite was used for the bench-scale chlorination testing. Chlorine demand trial tests were conducted to determine the dose requirements for the blackwater and mixed blackwater/graywater samples over specific exposure times and various temperatures to provide test solutions with the target concentration of free and/or total chlorine.

Following chlorination of the wastewater, and after a reaction time to represent vessel operations, each solution was mixed into artificial seawater, at various dilutions to simulate discharge into the ocean. The artifical sea water used was prepared using "Instant Ocean Sea Salt" and was added to laboratory ultra-pure water to produce a practical salinity unit (psu) of 32. A salinity of 32 psu is the average for ocean waters off the coast of Alaska.

After chlorinating the wastewater, blending with the seawater, and maintaining a constant temperature, subsamples were collected and tested for free and total chlorine at time intervals to document decay kinetics.

2. Study Methods

Sample Collection

The project study approach included the use of representative non-disinfected black-water and black water/gray-water samples. The black water samples were collected from the vessel Spirit of 98' (docked at the Goldbelt dock) by D. Wilson and B. Paulson between 0930 and 1130 PDT on June 15, 2006. The black water samples were collected from an inline port following the maceration process and prior to any disinfection of the blackwater. The blackwater/graywater mix samples were collected from the Alaska State ferry vessel Matanuska (docked at the Auke Bay ferry dock) by D. Wilson and B. Paulson between 1500 and 1630 PDT on June 14, 2006. Samples were drawn (pumped) directly from the vessel's graywater holding tank.

The samples were collected in 5-gallon low density polyethylene laboratory containers. The sample containers were placed in coolers with several bags of crushed ice, and CH2M HILL personnel shipped the samples using Federal Express next day delivery. The samples were received at the Applied Sciences Laboratory on Saturday June 17, 2006. The samples were placed in the lab's walk-in-cooler upon receipt, and stored there through out the duration of the study at 4°C. The sample chain-of-custody and sample receipt forms are presented in Attachment 2.

Analytical Methods

The analytical methods used during the chlorine decay task are presented in Table 1. All analytical testing were performed at CH2M HILL's Applied Sciences Laboratory in Corvallis, Oregon.

Table 1 Analytical Test Methods and Sample Storage Requirements

Name	Analytical Methods	Container[a]	Preservation	Minimum Sample Volume or Weight	Maximum Holding Time
Alkalinity	SM 2320.B	P,G	Refrigerate	200	14 d
Ammonia	SM 4500-NH3.G	P,G	H2SO4 pH < 2 Refrigerate	500	28 d
BOD5	SM 5210.B	P,G	Refrigerate	1,000	48 h
COD	SM 5220.D	P,G	H2SO4 pH < 2 Refrigerate	100	28 d
Conductivity	SM 2510.B	P,G	Refrigerate	500	28 d

Table 1 Analytical Test Methods and Sample Storage Requirements

Name	Analytical Methods	Container[a]	Preservation	Minimum Sample Volume or Weight	Maximum Holding Time
Free Chlorine [b]	SM4500-Cl-G	P,G	Analyze Immediately	500	0.25 h
Total Chlorine [b]	SM4500-Cl-G	P,G	Analyze Immediately	500	0.25 h
pH	SM4500-H-B	P,G	Analyze Immediately	500	0.25 h
TOC	SM 5310.C	G	H2SO4 pH < 2 Refrigerate	100	28 d
TSS	SM 2540.D	P,G	Refrigerate	200	7 d
Turbidity	SM 2130.B	P,G	Refrigerate, Store in Dark	100	48 h

a Polyethylene (P); glass (G), amber glass (AG).

b The chlorine measurement method is the DPD colorimetric test. This was selected because it's commonly used, easy, and fast. Since bromine (which is present in sea water) is a positive interference to the DPD test, method blank samples (samples with no chlorine added) were evaluated at each of the various sea water blend ratios and those concentrations of bromine did not show interfere with the total chlorine analysis. Bromine was found to interfere with the free chlorine measurement. Color and turbidity can interfere with the colorimetric test and this was compensated by using the sample to zero the spectrophotometer.

Decay Test Protocol

Several test conditions were evaluated in order to estimate the wastewater chlorine decay rates from the various vessel treatment systems. The test conditions are presented in Table 2. Samples were temperature-regulated during the demand and decay testing using laboratory precision incubators. Sodium Hypochlorite (NaOCl) was used as the chlorine source. All test data were recorded and documented using the standard lab chlorine demand/decay bench sheets. Each of the samples listed in Table 2 were evaluated for chlorine decay kinetics using the following protocol:

1. The wastewater samples were temperature regulated, using precision laboratory incubators, at 15-18°C for the blackwater and 18-22°C for the blackwater/graywater samples. The artificial sea water was temperature regulated at 12°C. After blending the wastewater and sea water, the samples were held at 12°C for the duration of the chlorine decay test.
2. The samples were first evaluated for chlorine demand. The objective is to determine the dose needed to achieve the target chlorine residual at a specifc reaction time. This process required multiple tests of adding various chlorine amounts to achieve the desired results. The target reaction time, chlorine dose, and temperature are presented in Table 2. These results were used to conduct the decay test.

Table 2
Matrix of Discharge Test Scenarios for Chlorine Decay Study

Test	Discharge Scenario	Effluent Salinity	Effluent Temp. (deg. C)	Chlorine Exposure in "Tank" (minutes)	Chlorine Conc. at Discharge (mg/L)	Mix Ratio (Seawater: Discharge) Test1/Test2	Ambient Temp. (C) & Salinity (psu)
BW-1	Black-water	27 psu	15 to 18 C	10	2 – 3	1 : 1 / 2 : 1	12 C / 32
BW-2	Black-water	27 psu	15 to 18 C	10	8 – 10	2 : 1 / 4 : 1	12 C / 32
BW-3	Black-water	27 psu	15 to 18 C	10	2 – 3	1 : 1 / 2 : 1	12 C / 32
BW-4	Black-water	27 psu	15 to 18 C	10	8 – 10	2 : 1 / 4 : 1	12 C / 32
BW-5	Black-water	27 psu	15 to 18 C	20	2 – 3	1 : 1 / 2 : 1	12 C / 32
BW-6	Black-water	27 psu	15 to 18 C	20	8 – 10	2 : 1 / 4 : 1	12 C / 32
BW-7	Black-water	27 psu	15 to 18 C	20	2 – 3	1 : 1 / 2 : 1	12 C / 32
BW-8	Black-water	27 psu	15 to 18 C	20	8 – 10	2 : 1 / 4 : 1	12 C / 32
WW-1	BW/GW Mix	15 psu	18 to 22 C	10	2 – 3	1 : 1 / 2 : 1	12 C / 32
WW-2	BW/GW Mix	15 psu	18 to 22 C	10	8 – 10	2 : 1 / 4 : 1	12 C / 32
WW-3	BW/GW Mix	15 psu	18 to 22 C	10	2 – 3	1 : 1 / 2 : 1	12 C / 32
WW-4	BW/GW Mix	15 psu	18 to 22 C	10	8 – 10	2 : 1 / 4 : 1	12 C / 32
WW-5	BW/GW Mix	15 psu	18 to 22 C	20	2 – 3	1 : 1 / 2 : 1	12 C / 32
WW-6	BW/GW Mix	15 psu	18 to 22 C	20	8 – 10	2 : 1 / 4 : 1	12 C / 32
WW-7	BW/GW Mix	15 psu	18 to 22 C	20	2 – 3	1 : 1 / 2 : 1	12 C / 32
WW-8	BW/GW Mix	15 psu	18 to 22 C	20	8 – 10	2 : 1 / 4 : 1	12 C / 32

The untreated blackwater and blackwater/graywater samples were collected from representative vessels.

3. For the decay testing chlorine was first added to the wastewater sample and gently stirred in a glass laboratory beaker, using a magnetic mixer and Teflon stir bar. The beaker was maintained at the desired temperature using an incubator, and the solution was allowed to react for the time presented in Table 2.

4. At the end of the reaction time, the sample was blended with seawater (pre-conditioned to the desired temperature by storing the bulk product in a precision incubator) at the desired mix ratio to produce a total volume of 500-750 ml (depending on the blending ratio) and gently stirred using the magnetic mixer for 5 minutes to thouroughly mix. The

artifical sea water used for blending was prepared using "Instant Ocean Sea Salt" and was added to laboratory ultra-pure water to produce a practicle salinity unit (psu) of 32.

5. The chlorinated wastewater-sea water blend sample was transferred to eight 40-ml VOA vial containers with no headspace, placed in a precision lab incubator at 12°C, and the residual chlorine monitored over time to develop a graph to illustrate decay kinetics. One VOA vial was used for each chlorine measurement.

6. Free and total chlorine measurements were made at time intervals selected to model the decay kinetics for each sample. The time intervals varied for each sample in order to model the specific decay rate for that sample and test condition. The time intervals are in each of the diagrams presented in the results section, along with the corresponding total and/or free chlorine measurements. The chlorine measurement method used was the DPD colorimetric test (refer to Table 1 for analytical methods).

3. Study Results

The results of this chlorine decay study are presented in the stages that the study occurred; first wastewater sample characterization, then chlorine break-point determination, and finally the chlorine demand and decay experiments.

Wastewater Characterization

The wastewater characterization data are presented in Table 3. Attachment 3 presents wastewater characterization data for small commercial passenger vessels from a 2004 ADEC report. These data are included in Table 3 for reference and comparison.

Table 3 – Sample Characterization Data

Wastewater Characterization Data					
Client		ADEC	ADEC	ADEC	ADEC
Type		Blackwater	Blackwater	Black Water - Gray Water Mix	Black Water - Gray Water Mix
Ship		Spirit of 98'	2004 ADEC Report Average	Matanuska	2004 ADEC Report Average
Laboratory ID		F1981-01	NA	F1981-02	NA
Test Results					
Alkalinity	Mg/L as $CaCO_3$	375	120	150	141
Ammonia	mg/L as N	78	10	22	18
BOD_5	mg/L	164	79	690	210
COD	mg/L	876	765	1276	731
Conductivity	umhos/cm	26,500	31,600	5,910	23,800
pH	Units	7.8	7.7	5.6	7.3
TOC	mg/L	236	164	148	232
TSS	mg/L	95	112	145	105
Turbidity	cm^{-1}	80	NA	313	NA

Break Point Chlorination

Wastewater samples exhibit a chlorine demand based on reactions with any reducing agents, ammonia, some inorganic species, and organic material in the wastewater. The chlorine demand is the amount of free chlorine required to reach a specific treatment goal, which may be the breakpoint chlorination point, a free residual value after breakpoint chlorination is achieved, or in the case of this study, the amount of free chlorine required to reach the target combined chlorine residual.

Free chlorine reacts with ammonia very quickly to form chloramines. If there is ammonia in the wastewater sample, then the only way to get free chlorine is to add chlorine until all the ammonia is gone, add more to react with the chloramines, then free chlorine is produced. The point where free chlorine is produced is the chlorination break-point.

The results of the break-point chlorination testing show that there is enough ammonia present in the wastewater samples to convert the free chlorine added to choramines. Under these conditions there is no free chlorine present. This holds true for these wastewater samples up to a very high dose of chlorine (approximately 350 mg/L for black water and 250 mg/L for black water/gray water mix), where breakpoint chlorination occurs and free chlorine will start to increase with dose. Figures 2 and 3 illustrate the results of the break-point chlorination tests for blackwater and blackwater/graywater samples. Because of the high ammonia levels, and the corresponding very high chlorine dose to reach breakpoint, the decay testing for this study focused on a combined chlorine dose to represent actual treatment conditions on the vessels.

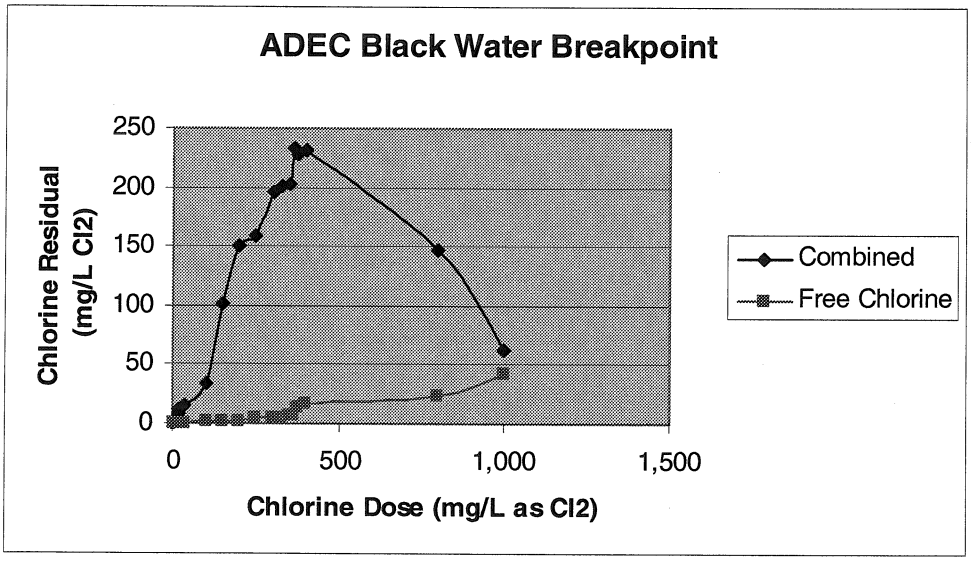


Figure 2. Black water breakpoint chlorination curve

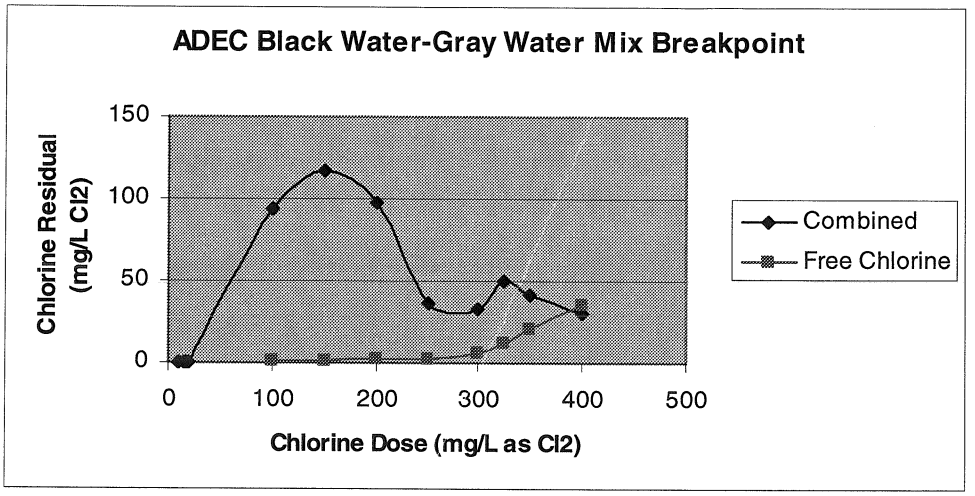


Figure 3. Black water-gray water mix breakpoint chlorination curve

Chlorine Demand Results

The chlorine demand is the amount of free chlorine required to reach a specific treatment goal, which may be the breakpoint chlorination point, a free residual value after breakpoint chlorination is achieved, or in the case of this study, the amount of free chlorine required to reach the target combined chlorine residual.

Demand tests were conducted to determine the chlorine dose needed to achieve the combined chlorine concentration specified in Table 2 for the decay testing. These laboratory study results show that the chlorine demand for blackwater and mixed blackwater-graywater was comparable for the samples tested. The chlorine demand curves are presented below in Figures 4 and 5. For blackwater, a chlorine dose of 15 mg/L (as Cl2) resulted in a chlorine residual of 7.5 mg/L. For the blackwater/graywater mix, a chlorine dose of 15 mg/L (as Cl2) resulted in a chlorine residual of 6 mg/L. A chlorine dose of 10 mg/L (as Cl2) resulted in a chlorine residual of 3.5 mg/L in blackwater and 3 mg/L in blackwater/graywater mix.

Through the chlorination process several classes of disinfection by-products are formed including trihalomethanes (THM's) and haloacidacids (HAA's). With high organic content wastewater, and in combination with the bromide and chloride based inorganic species in sea water, the disinfection byproduct formation could be significant if the wastewater is chlorinated to breakpoint, and free chlorine is present (reference Figure 1). However, since the chlorine level typically added to these wastewater systems is below breakpoint, and since there is ammonia in the wastewater samples, the predominant form of chlorine is as combined chlorine. Because combined chlorine (chloramines) produces limited disinfection by products, disinfection byproduct testing was not included with this task.

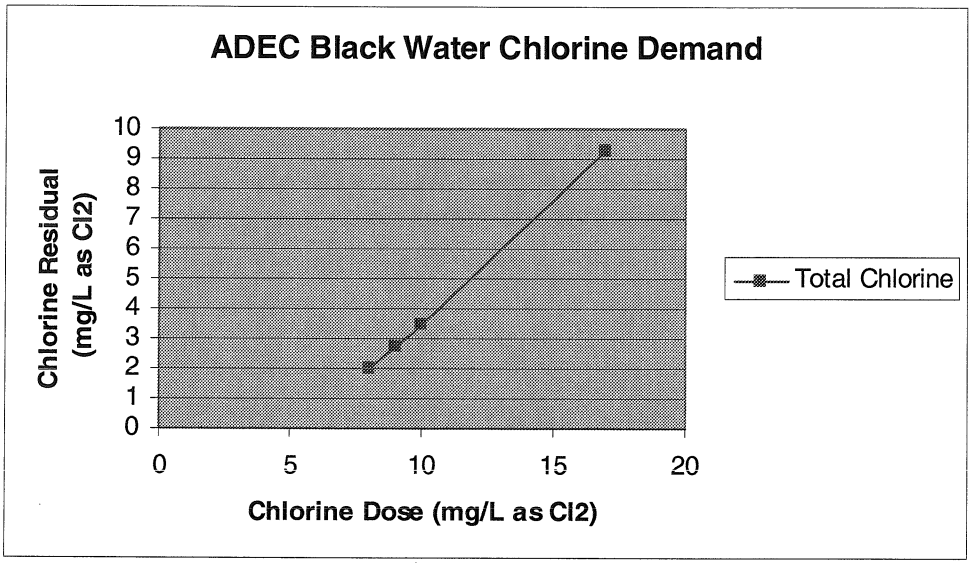


Figure 4. Black water chlorine demand results

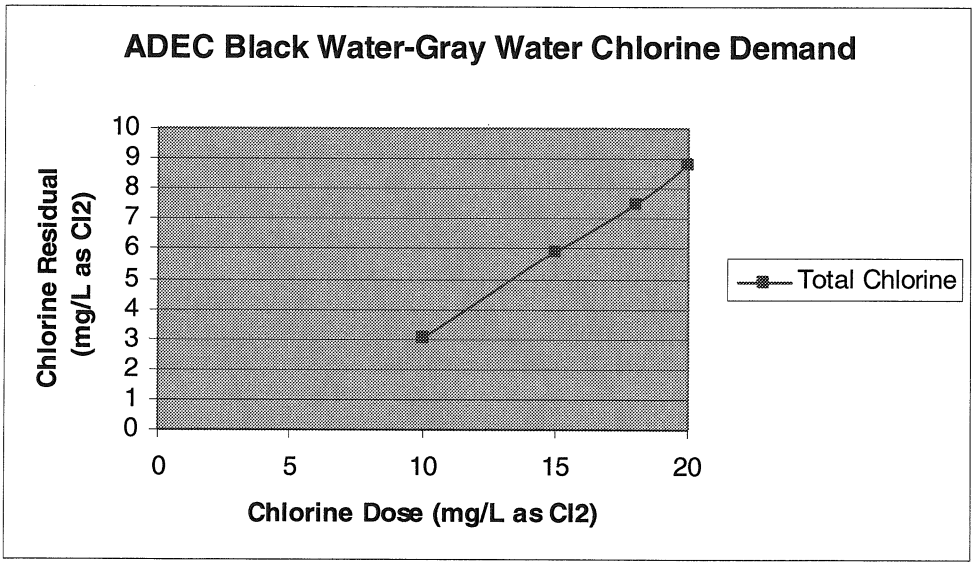


Figure 5. Black water-graywater mix chlorine demand results

Chlorine Decay Study Results

Free chlorine will decay at a predictable and relatively quick rate (minutes, hours, or sometimes days) depending on conditions (temperature, pH, and dose). Combined chlorine (chloramines) decays at a predictable and slow rate (days) dependent on conditions of reaction.

Figure 6 through 13 present the results of the chlorine decay studies for each test condition presented in Table 2. Replicate tests were performed for each condition and both test results are plotted on each figure. For both wastewater samples, a total chlorine residual of 3-4 mg/L (after tank reaction time) required approximately 24-48 hours of decay time after sea water blending to achieve a level below 0.1 mg/L. For both wastewater samples, a total chlorine residual of 8-10 mg/L (after tank reaction time) required approximately 72-96 hours of decay time after sea water blending to achieve a level below 0.1 mg/L. The decay test data are included in Attachment 4.

The focus of this decay study was on combined chlorine. The data tables show some low level readings of free chlorine, especially in samples after blending with sea water. With the considerable amount of ammonia in the samples, relative to the chlorine dose, there is theoretically no free chlorine present in the samples. The free chlorine readings are believed to be interference, as described in the test method, caused by combined chlorine while using the DPD measurement method.

Alternate chlorine measurement methods can be used to measure combined chlorine and the individual chloramines species. However, since the focus of this study was on combined chlorine, and considering the time and expense with the alternate chlorine procedures, the DPD method was used, and the interference should be considered when evaluating the results.

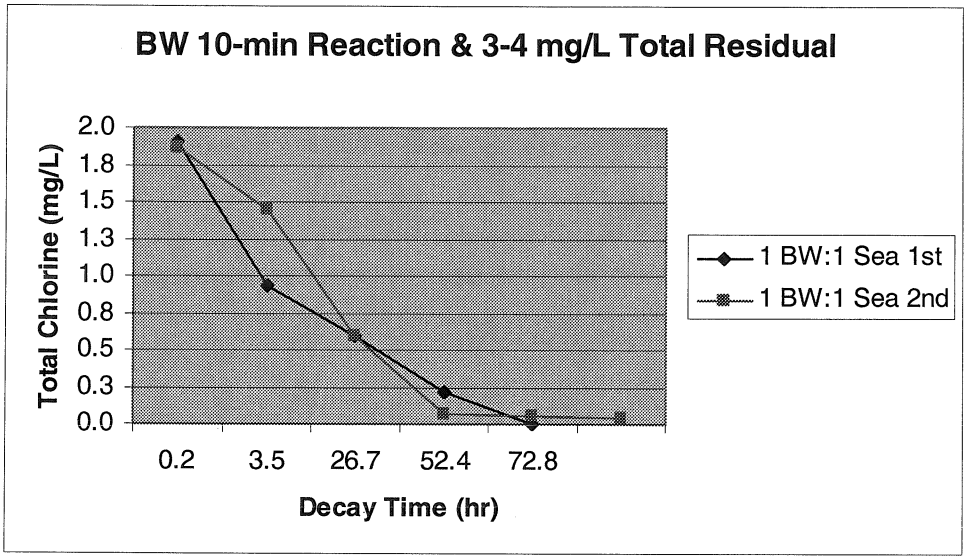


Figure 6a. Blackwater with 3-4 mg/L chlorine at discharge (10 minute exposure & 1:1 mix ratio with seawater)

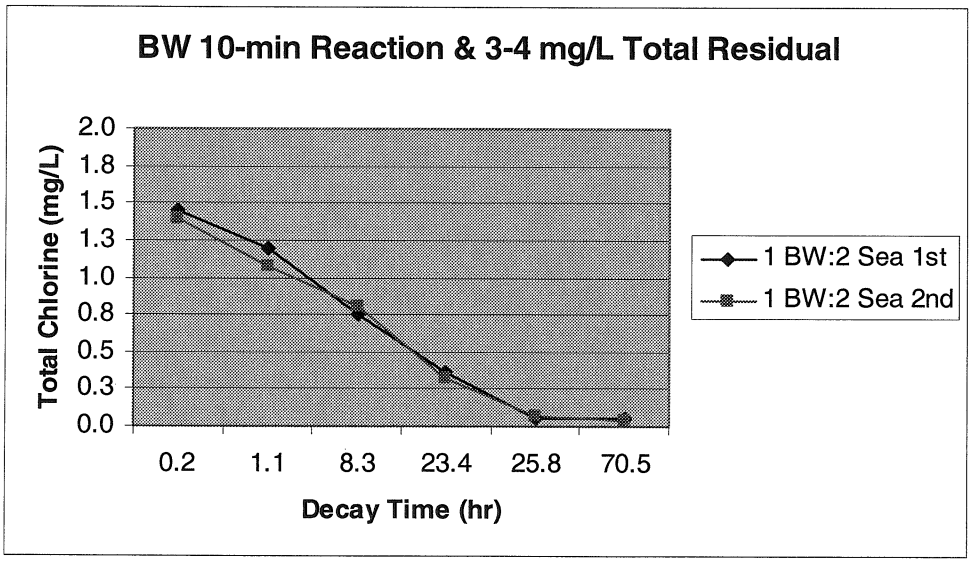


Figure 6b. Blackwater with 3-4 mg/L chlorine at discharge (10 minute exposure& 2:1 mix ratio with seawater)

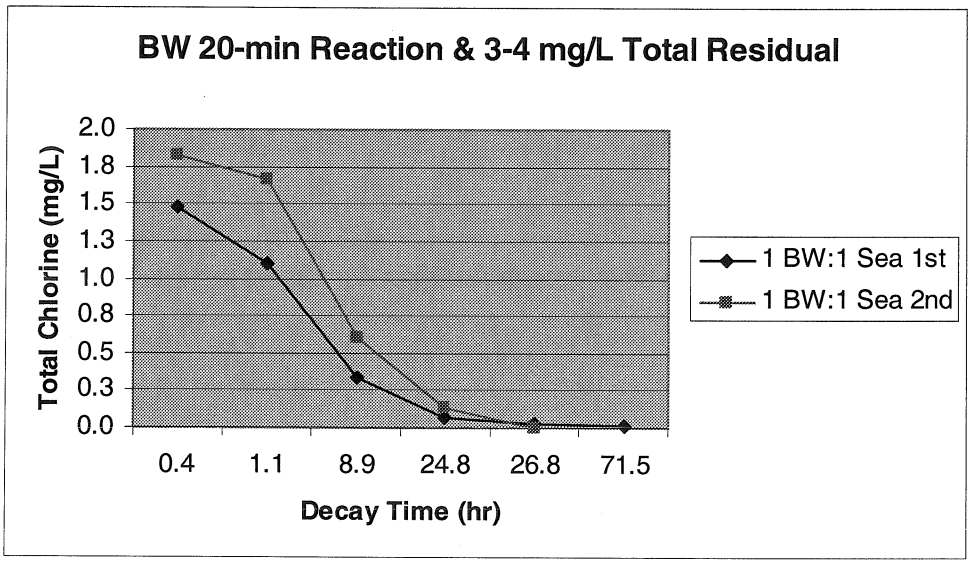


Figure 7a. Blackwater with 3-4 mg/L chlorine at discharge (20 minute exposure & 1:1 mix ratio with seawater)

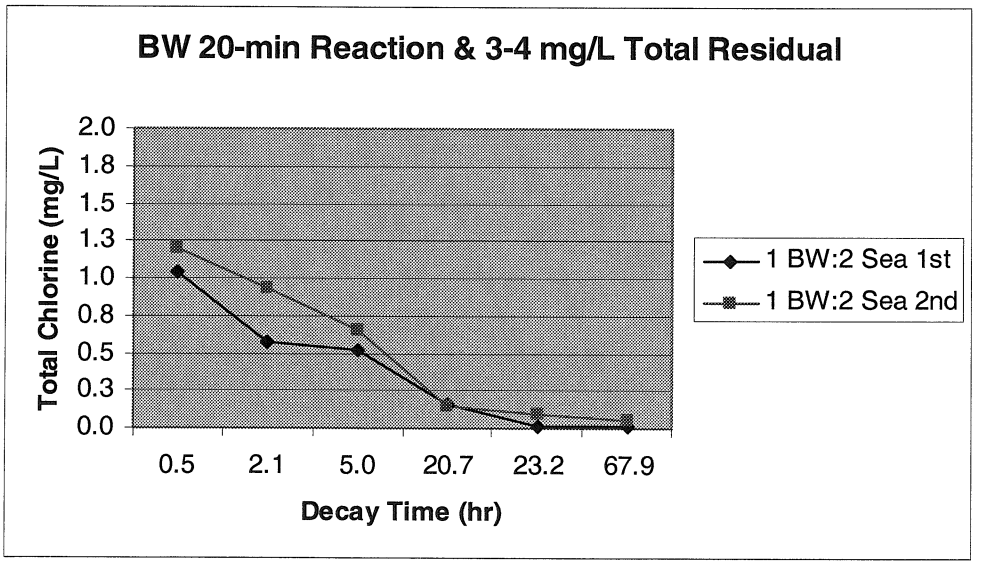


Figure 7b. Blackwater with 3-4 mg/L chlorine at discharge (20 minute exposure& 2:1 mix ratio with seawater)

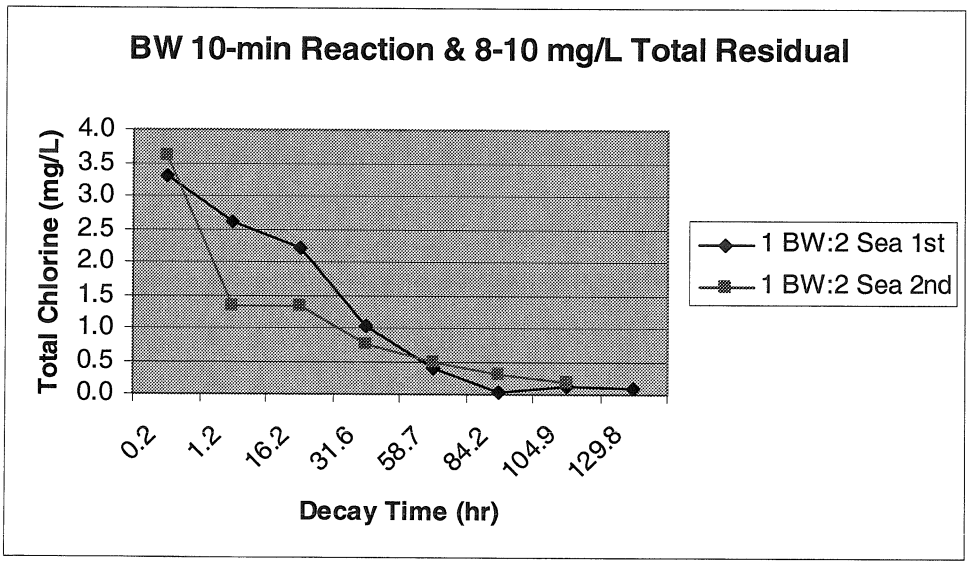


Figure 8a. Blackwater with 8-10 mg/L chlorine at discharge (10 minute exposure & 2:1 mix ratio with seawater)

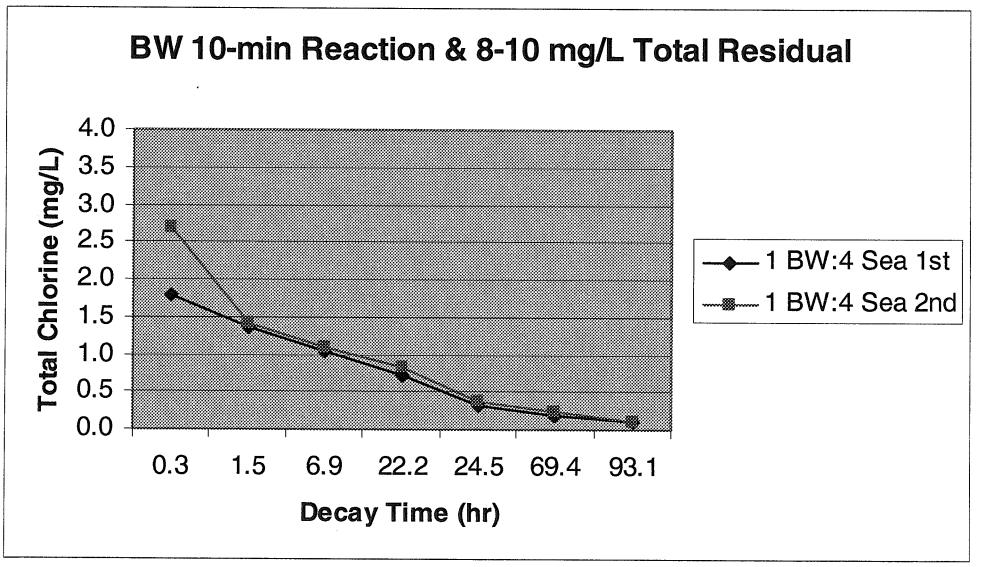


Figure 8b. Blackwater with 8-10 mg/L chlorine at discharge (10 minute exposure & 4:1 mix ratio with seawater)

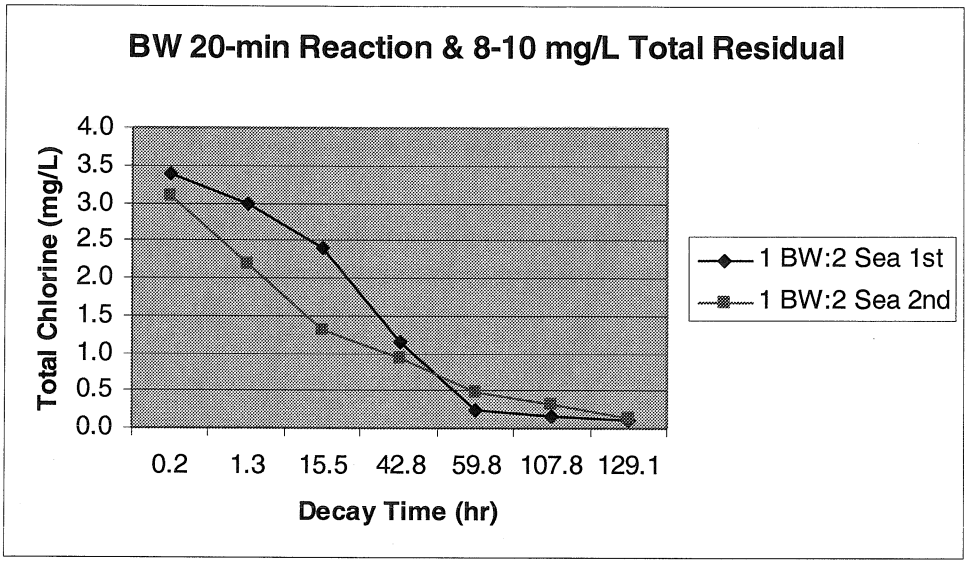


Figure 9a. Blackwater with 8-10 mg/L chlorine at discharge (20 minute exposure & 2:1 mix ratio with seawater)

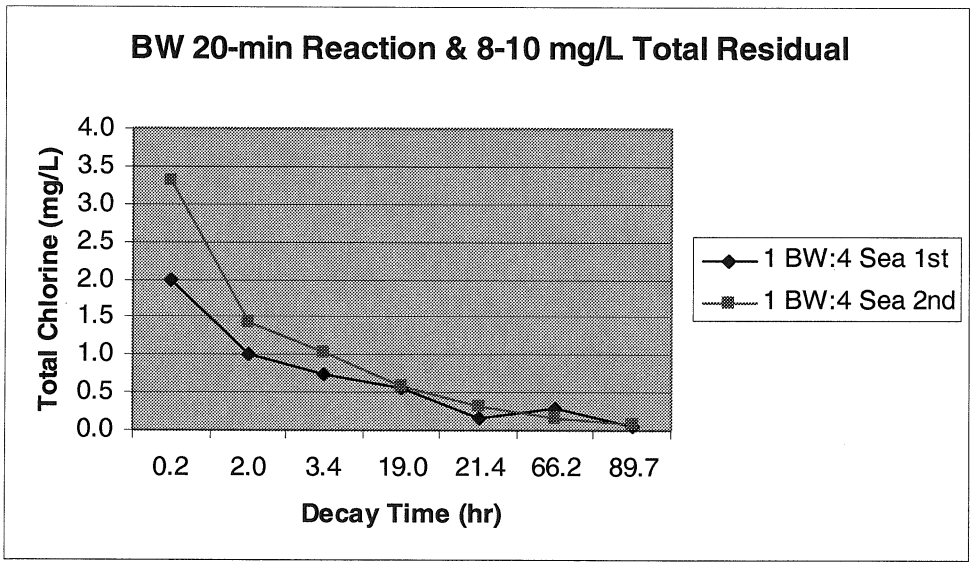


Figure 9b. Blackwater with 8-10 mg/L chlorine at discharge (20 minute exposure & 4:1 mix ratio with seawater)

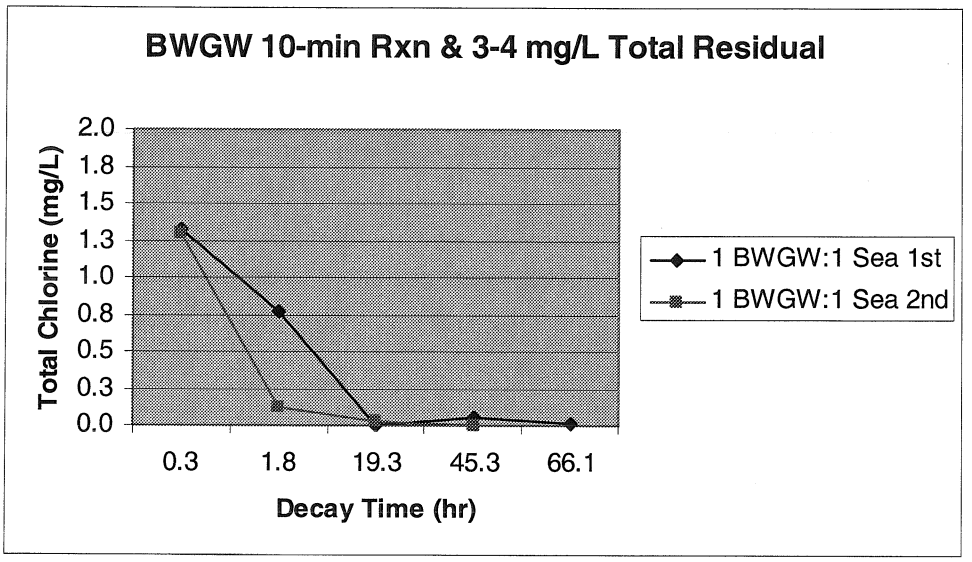


Figure 10a. Blackwater/Graywater mix with 3-4 mg/L chlorine at discharge (10 minute exposure & 1:1 mix ratio with seawater)

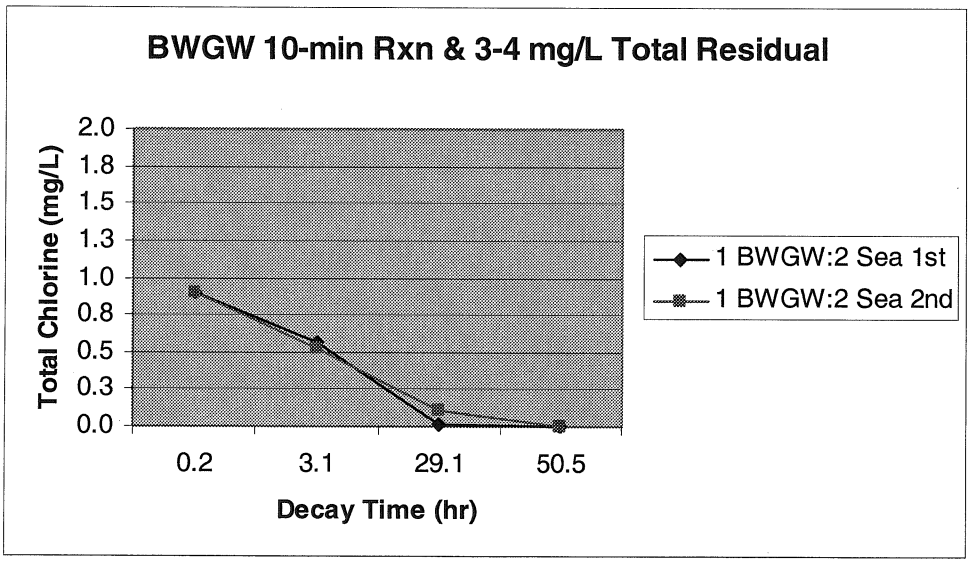


Figure 10b. Blackwater/Graywater mix with 3-4 mg/L chlorine at discharge (10 minute exposure & 2:1 mix ratio with seawater)

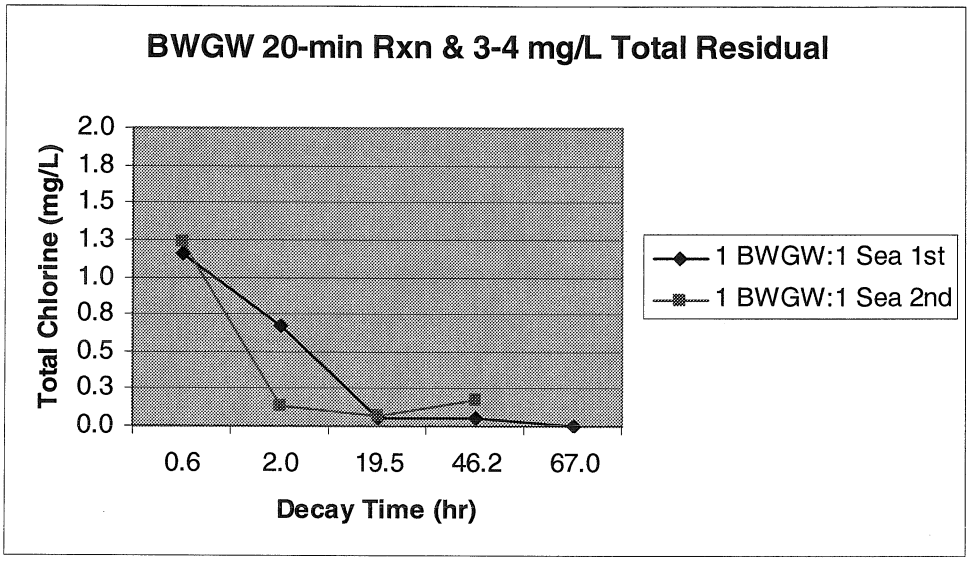


Figure 11a. Blackwater/Graywater mix with 3-4 mg/L chlorine at discharge (20 minute exposure & 1:1 mix ratio with seawater)

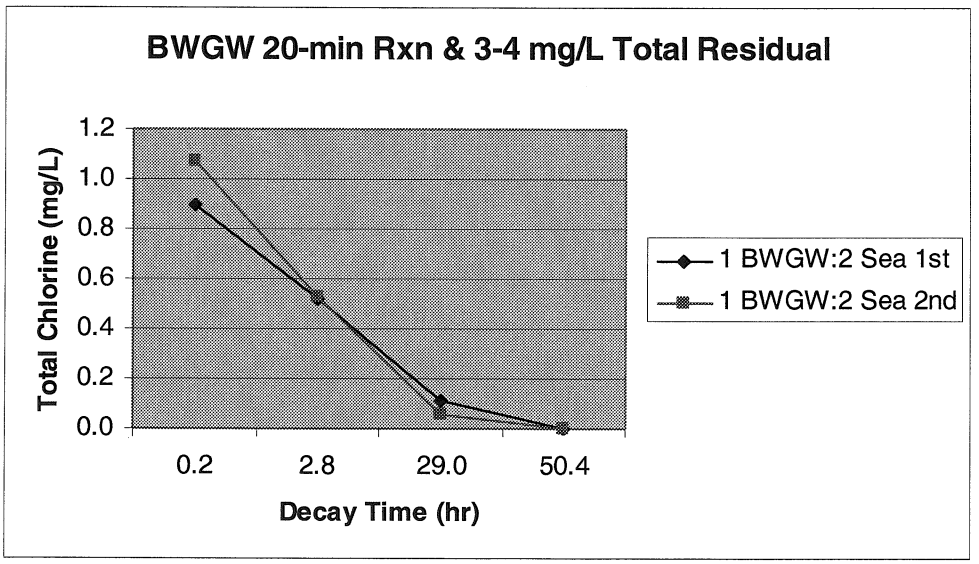


Figure 11b. Blackwater/Graywater mix with 3-4 mg/L chlorine at discharge (20 minute exposure & 2:1 mix ratio with seawater)

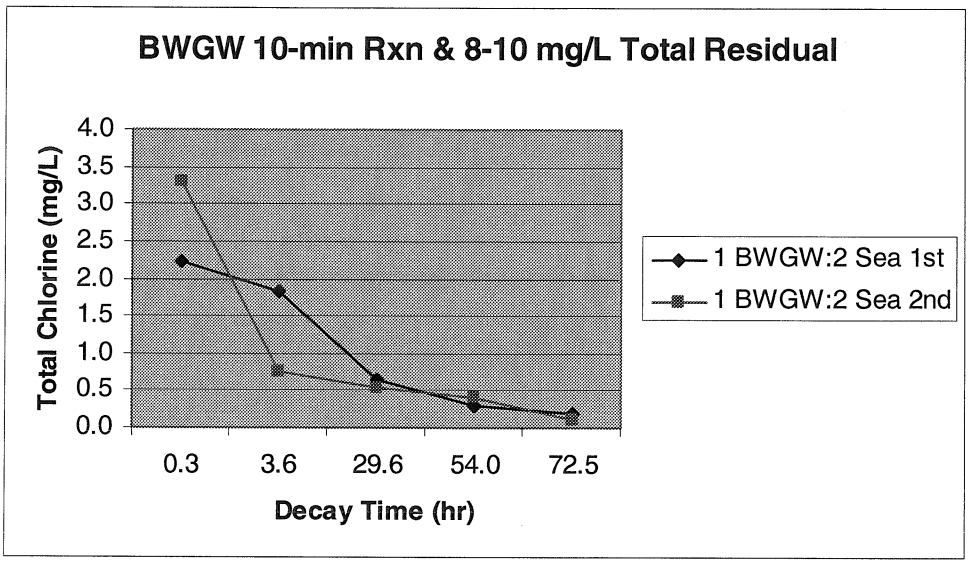


Figure 12a. Blackwater/Graywater mix with 8-10 mg/L chlorine at discharge (10 minute exposure & 2:1 mix ratio with seawater)

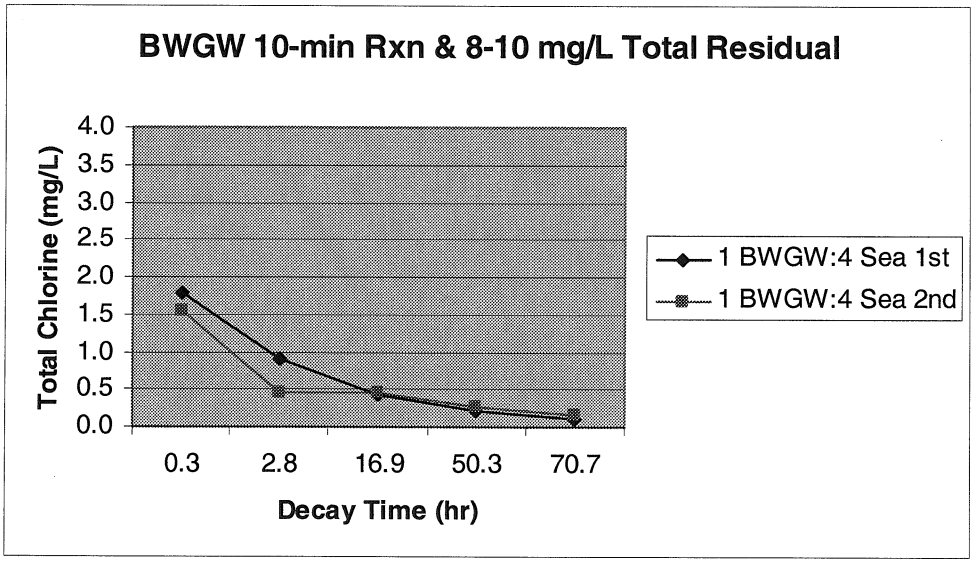


Figure 12b. Blackwater/Graywater mix with 8-10 mg/L chlorine at discharge (10 minute exposure & 4:1 mix ratio with seawater)

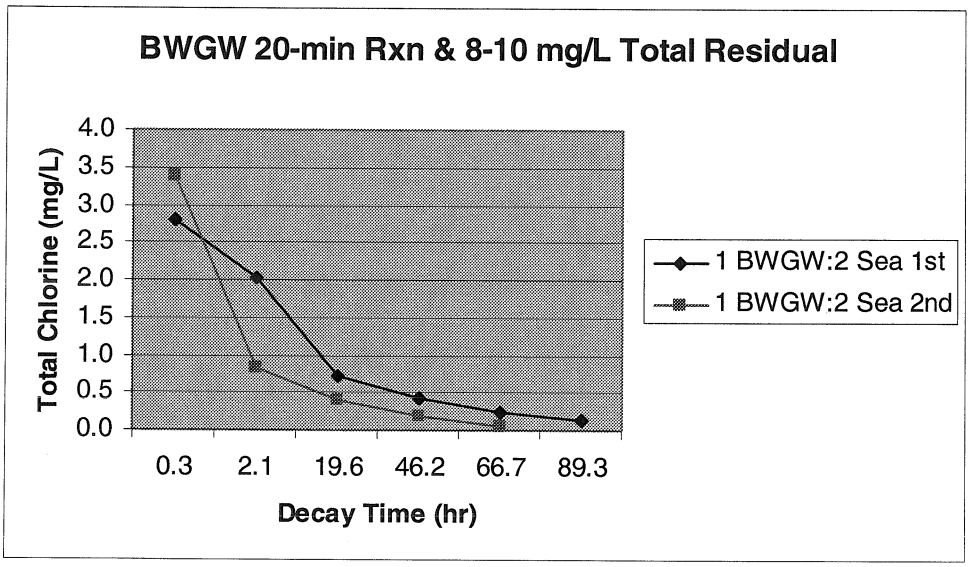


Figure 13a. Blackwater/Graywater mix with 8-10 mg/L chlorine at discharge (20 minute exposure & 2:1 mix ratio with seawater)

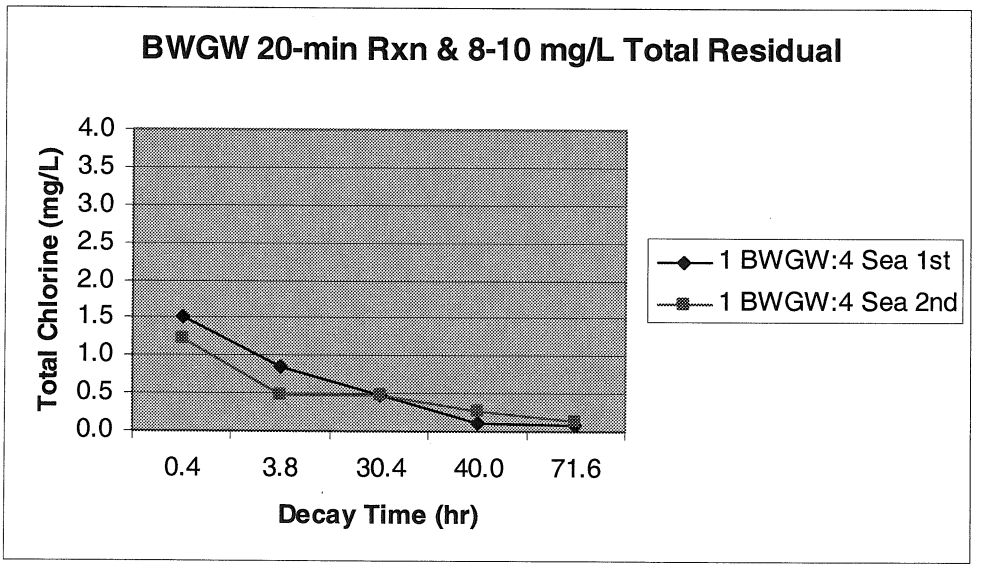


Figure 13b. Blackwater/Graywater mix with 8-10 mg/L chlorine at discharge (20 minute exposure & 4:1 mix ratio with seawater)

Chlorine Decay Study Conclusions

This chlorine decay study was developed and performed to provide a representation of the potential ranges of chlorine decay rates for chlorinated wastewaters discharged from small ships to the marine surface waters. The following items summarize the key findings and conclusions:

- The break-point chlorination tests show that the wastewater ammonia concentrations create choramines (combined chlorine) and there was essentially no free chlorine present in the wastewater. The lab tests show that very high doses of chlorine (approximately 350 mg/L for black water and 250 mg/L for black water/gray water mix) were needed to attain breakpoint chlorination where free chlorine would be produced.

- Chlorine demand in the blackwater and mixed blackwater-graywater samples tested were roughly equivalent. Both blackwater and blackwater/graywater mixed samples received a chlorine dose of 15 mg/L (as Cl2) and these resulted in total residual chlorine level of 7.5 mg/L in blackwater and 6 mg/L in the blackwater/graywater mix sample. A chlorine dose of 10 mg/L (as Cl2) resulted in a chlorine residual of 3.5 mg/L in blackwater and 3 mg/L in blackwater/graywater mix.

- The focus of this decay study was on combined chlorine, since no free chlorine was present in the samples because of the ammonia concentrations in the wastewater. Combined chlorine (chloramines) decays at a predictable and slow rate (days) dependent on conditions of reaction, while free chlorine decays at a relatively quick rate.

- Results of the chlorine decay studies show that a total chlorine residual of 3-4 mg/L required approximately 24-48 hours of decay time after discharge to marine waters to reduce to a level below 0.1 mg/L. Both blackwater and mixed blackwater-graywater samples with a total chlorine residual of 8-10 mg/L required approximately 72-96 hours of decay time after discharge to marine waters to reduce to a level below 0.1 mg/L.

- Effective chlorination of vessel blackwater and mixed blackwater-graywater without creating excess chlorine residual in the discharged waters is challenging. Chlorine dosing of blackwater and mixed blackwater-graywater with sufficient chlorine to provide adequate chlorine residual for effective bacteria destruction will result in concentrations discharged that are substantially above the Alaska water quality standards. Vessel discharge mixing zones and discharge dilutions are needed for the chlorine residual concentrations to approach Alaska water quality standards.

ATTACHMENT 1

2004 Small Commercial Passenger Vessels Discharge Status and Wastewater Treatment

Attachment 1

2004 Small[1] Commercial Passenger Vessels Discharge Status and Wastewater Treatment

Vessel Operator	Vessel Name	Passenger Capacity (lower berth)	Crew Capacity	Total Persons on Board	Blackwater Treatment System Manufacturer	Graywater treatment	Discharging in Alaska[3] & Subject to sampling program		Type of Treatment System
							BW	GW	
Alaska Marine Highway System	*Columbia*	157	66	223	Exceltec	Mixed with BW	Yes	Yes	Macerator Chlorinating System
Alaska Marine Highway System	*Kennicott*	162	42	204	Orca	Mixed with BW	Yes	Yes	Macerator Chlorinating System
Alaska Marine Highway System	*Malaspina*	138	50	188	Exceltec	Mixed with BW	Yes	Yes	Macerator Chlorinating System
Alaska Marine Highway System	*Matanuska*	136	50	186	Exceltec	Mixed with BW	Yes	Yes	Macerator Chlorinating System
Alaska Marine Highway System	*Taku*	55	42	97	Effluent Technology	Mixed with BW	Yes	Yes	Macerator Chlorinating System
America West Steamshp	*Empress of the North*	see total	see total	320	Orca	Chlorine	No	No	Macerator Chlorinating System
CruiseWest	*Spirit of 98*	96	26	122	Red Fox	None	Yes	Yes	Biological Chemical
CruiseWest	*Spirit of Alaska*	78	21	99	Omnipure	None	Yes	Yes	Macerator Chlorinating System
CruiseWest	*Spirit of Columbia*	78	21	99	Omnipure	None	Yes	Yes	Electrocatalytic
CruiseWest	*Spirit of Discovery*	84	21	105	Red Fox	None	Yes	Yes	Biological Chemical
CruiseWest	*Spirit of Endeavour*	102	28	130	Omnipure	None	Yes	Yes	Electrocatalytic
CruiseWest	*Spirit of Oceanus*	114	64	178	Hamworthy	None	Yes	Yes	Biological & Filtration
Society Expedition	*World Discoverer*	170	90	260	Biological	Chlorine	No	No	Biological
Glacier Bay	*Wilderness Adventurer*	69	23	92	Omnipure 12 MX	Mixed with BW	Yes	Yes	Electrocatalytic
Glacier Bay	*Wilderness Discoverer*	87	23	110	Omnipure 12 MX	Mixed with BW	Yes	Yes	Electrocatalytic
Lindblad Expeditions	*Sea Bird*	70	28	98	Omnipure 12M	Chlorine	Yes	Yes	Electrocatalytic
Lindblad Expeditions	*Sea Lion*	68	28	96	Omnipure 12M	Chlorine	Yes	Yes	Electrocatalytic
New World Management	*Clipper Odyssey*	128	76	204	Consillium Neptumatic	Chlorine	Yes	Yes	Macerator Chlorinating System
New World Management	*Yorktown Clipper*	138	37	175	Omnipure 12MX824-27	Chlorine	Yes	Yes	Electrocatalytic

[1]A small vessel has overnight accommodations for 50-249 passengers. A large vessel has overnight accommodations for 250 or more passengers.

[2]Alaska water extends 3 miles from the coastline and includes the Alexander Archipelago. Vessels discharging in Alaska water must sample their wastewater twice per season.

Table source is ADEC, last updated 9-30-2004.

ATTACHMENT 2

Chain of Custody Doccument and Sample Reciept Forms

Analytica Chain of Custody Form

F1986 Page 1 of 1

ANALYTICA GROUP

12189 Pennsylvania St. Thornton, CO 80241 (303) 469-8868 (303) 469-5254 fax

5438 Shaune Drive Juneau, AK 99801 (907) 780-6668 (907) 780-6670 fax

5761 Silverado Way, # N Anchorage, AK 99518 (907) 258-2155 (907) 258-8634 fax

3330 Industrial Ave. Fairbanks, AK 99701 (907) 456-3116 (907) 456-3125 fax

Pouch 34043 Prudhoe Bay, AK 99734 (907) 659-2145 (907) 659-2146 fax

Chain of Custody No: 43433

Client Name & Address: CH2M Hill	**Project Name:** ADEC-Chlorine Decay Study	**To be Completed by Analytica**
	Public Water System ID#:	Quote ID No: LGN:
	Results to STATE: YES NO	
Contact Person: David Wilson	Data Deliverables: Level I Level II Level III Level IV	**Report to:**
Phone No: 425-453-5000	EDD: YES NO Type of EDD:	
Fax No:	Requested TAT: 10 days **RUSH** (lab authorization required)	**Invoice to:**
E-mail:	Results Due Date:	
Special Instructions:		**P.O. or Contract No:**

Lab Bottle Order No:	Sample Description	Date Sampled	Time Sampled	Matrix (S-DW-WW-Other)	No. of Containers	Requested Analysis/Method: Lab Tests per Study Plan	MS/MSD ?	Comments
GW/BW-1	(Matanuska)	6-14-06	1500		1			
GW/BW-2	(")	"	"		1			
GW/BW-3	"	"	"		1			
BW-1	(Spirit 98')	6-15-06	1000		1			
BW-2	(")	"	"		1			
BW-3	(")	"	"		1			

Collected/Relinquished by:	Date	Time	Received by:	Date	Time
[signature]	6-15-06	1315	ASL Treatability	6-17-06	
Relinquished by:	Date	Time	Received by: Staff (Ryan Armstrong)	Date	Time
			Daisy Hilliard	6-21-06	10:44
Relinquished by:	Date	Time	Received by:	Date	Time
Name of Sampler: (printed)					

To be Completed by Analytica

Chain-of-Custody Seal: Intact Broken Absent

Location Rcvd/Temp on Arrival:

THO ____C JUN ____C ANC ____C FAI ____C PB ____C

Thermometer ID # ____ Measurement Method: Temp. Blank Other

Shipping Method/Tracking Number:

CH2MHILL
Analytical Services

Sample Receipt Record

Batch Number: F1986 Date received: 6-17-06

Client/Project: ADEC Chlorine Decay Study Rec'd by ASL Treatability Staff

VERIFICATION OF SAMPLE CONDITIONS (verify all items) * HD = Client Hand delivered Samples

Observation	YES	NO
Radiological Screening for AFCEE		✓
Were custody seals intact and on the outside of the cooler?		
If yes, Where? Front ✓ Rear ✓ Lt Side ____ Rt Side ____ ~~Red~~	✓	
Type of packing material: (Ice) Blue Ice Bubble wrap	✓	
Was the Chain of Custody inside the cooler?	✓	
Was the Chain of Custody properly filled out?	✓	
Were the sample containers in good condition?	✓	
Containers supplied by ASL?	✓	
Any sample with < 1/2 holding time remaining? If so contact LPM		✓
Was there ice in the cooler? Enter temp. C Yes, per Ryan Armstrong conversation	✓	
All VOCs free of air bubbles ?		NA

VERIFICATION OF SAMPLE PRESERVATION

Sample No	Nutrients pH <2	Metals pH <2	Volatiles pH <2	Cyanides pH >12	TOC pH <2	TOX pH <2	Other (specify)	N/A (soils/unpres)
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26								
27								

LOGIN AND pH VERIFICATIONS PERFORMED BY

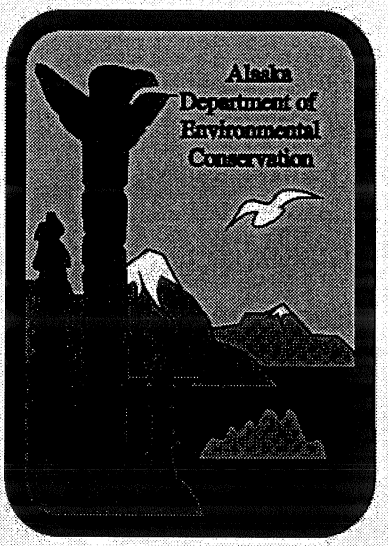
Daisy Hutchard 8-18-06 16:02
Date/Time

Date/Time

Sample was received by treatability staff on 6-17-06 DOH 6-21-06. Armstrong from a conversation with Ryan

ATTACHMENT 3

Small Commercial Passenger Vessel Wasewater Characterization Data



Assessment of Cruise Ship and Ferry Wastewater Impacts in Alaska

Alaska Department of Environmental Conservation

Commercial Passenger Vessel Environmental Compliance Program

February 9, 2004

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:

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

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.

ATTACHMENT 4

Decay Testing Data

ADEC Chlorine Demand/Decay - Black Water Test Series #1										
Client ID	Lab ID	FP Dose	Free Residual	Free Demand	Total Residual	FP Temp.	FP Start	FP Take-Off	FP Time (H:M)	FP Time (Hr.)
Blackwater	BW-1-test1	12.50				12	6/23/06 9:15			
10 min			0.10	12.40	2.76	12		6/23/06 9:25	0:10	0.17
3-4 mg/L Total	added seawater		0.36	12.14	1.90	12		6/23/06 9:27	0:12	0.20
1:1			0.36	12.14	0.93	12		6/23/06 12:43	3:28	3.47
			0.00	12.50	0.60	12		6/24/06 11:56	26:41	26.68
			0.05	12.45	0.21	12		6/25/06 13:41	52:26	52.43
			0.09	12.41	0.00	12		6/26/06 10:05	72:50	72.83
Blackwater	BW-2-test1	17.00				12	6/22/06 1:25			
10 min			0.18	16.82	9.30	12		6/22/06 1:35	0:10	0.17
8-10 mg/L	added seawater		0.84	16.16	3.30	12		6/22/06 1:38	0:13	0.22
2:1			0.83	16.17	2.60	12		6/22/06 2:36	1:11	1.18
			0.16	16.84	2.20	12		6/22/06 17:38	16:13	16.22
			0.12	16.88	1.03	12		6/23/06 9:00	31:35	31.58
			0.13	16.87	0.40	12		6/24/06 12:10	58:45	58.75
			0.05	16.95	0.04	12		6/25/06 13:40	84:15	84.25
			0.13	16.87	0.13	12		6/26/06 10:21	104:56	104.93
			0.07	16.93	0.09			6/27/06 11:15	129:50	129.83
Blackwater	BW-3-test1	11.00				12	6/23/06 10:38			
10 min			0.09	10.91	2.44	12		6/23/06 10:48	0:10	0.17
3-4 mg/L	added seawater		0.58	10.42	1.86	12		6/23/06 10:51	0:13	0.22
1:1			0.14	10.86	1.44	12		6/23/06 11:40	1:02	1.03
			0.05	10.95	0.59	12		6/23/06 20:01	9:23	9.38
			0.00	11.00	0.07	12		6/24/06 11:53	25:15	25.25
			0.04	10.96	0.05			6/24/06 13:48	27:10	27.17
			0.00	11.00	0.04	12		6/26/06 10:28	71:50	71.83
Blackwater	BW-4-test1	18.00				12	6/23/06 11:20			
10 min			0.22	17.78	10.20	12		6/23/06 11:30	0:10	0.17
8-10 mg/L	added seawater		1.20	16.80	3.60	12		6/23/06 11:33	0:13	0.22
2:1			0.62	17.38	1.32	12		6/23/06 12:22	1:02	1.03
			0.00	18.00	1.33	12		6/23/06 20:06	8:46	8.77
			0.00	18.00	0.75	12		6/24/06 12:05	24:45	24.75
			0.00	18.00	0.47	12		6/24/06 13:53	26:33	26.55
			0.00	18.00	0.31	12		6/26/06 10:34	71:14	71.23
			0.00	18.00	0.18	12		6/27/06 11:18	95:58	95.97
Blackwater	BW-5-test1	13.50				12	6/23/06 11:10			
20 min			0.28	13.22	2.74	12		6/23/06 11:30	0:20	0.33
3-4 mg/L	added seawater		0.63	12.87	1.48	12		6/23/06 11:33	0:23	0.38
1:1			0.34	13.16	1.10	12		6/23/06 12:15	1:05	1.08
			0.00	13.50	0.33	12		6/23/06 20:06	8:56	8.93
			0.00	13.50	0.07	12		6/24/06 12:00	24:50	24.83
			0.00	13.50	0.03	12		6/24/06 14:00	26:50	26.83
			0.00	13.50	0.01	12		6/26/06 10:39	71:29	71.48
Blackwater	BW-6-test1	18.00				12	6/22/06 2:15			
20 min			0.40	17.60	9.60	12		6/22/06 2:25	0:10	0.17
8-10 mg/L	added seawater		1.26	16.74	3.40	12		6/22/06 2:28	0:13	0.22
2:1			0.40	17.60	3.00	12		6/22/06 3:30	1:15	1.25
			0.23	17.77	2.40	12		6/22/06 17:45	15:30	15.50
			0.11	17.89	1.15	12		6/23/06 21:00	42:45	42.75
			0.02	17.98	0.24	12		6/24/06 14:05	59:50	59.83
			0.00	18.00	0.15	12		6/26/06 14:05	107:50	107.83
			0.03	17.97	0.10	12		6/27/06 11:23	129:08	129.13
Blackwater	BW-7-test1	10.00				12	6/23/06 15:52			
20 min			0.17	9.83	3.60	12		6/23/06 16:02	0:10	0.17
3-4 mg/L	added seawater		1.00	9.00	1.62	12		6/23/06 16:08	0:16	0.27
1:1			0.73	9.27	1.66	12		6/23/06 17:08	1:16	1.27
			0.06	9.94	0.61	12		6/23/06 20:23	4:31	4.52
			0.00	10.00	0.13	12		6/24/06 11:44	19:52	19.87
			0.04	9.96	0.00	12		6/24/06 14:11	22:19	22.32
Blackwater	BW-8-test1	18.50				12	6/23/06 13:52			
20 min			0.23	18.27	8.90	12		6/23/06 14:12	0:20	0.33
8-10 mg/L	added seawater		1.07	17.43	3.10	12		6/23/06 14:15	0:23	0.38
2:1			0.21	18.29	2.20	12		6/23/06 15:18	1:26	1.43
			0.00	18.50	1.31	12		6/23/06 20:32	6:40	6.67
			0.08	18.42	0.93	12		6/24/06 11:48	21:56	21.93
			0.00	18.50	0.49	12		6/24/06 14:14	24:22	24.37
			0.00	18.50	0.33	12		6/26/06 10:15	68:23	68.38
			0.00	18.50	0.14	12		6/27/06 11:26	93:34	93.57

ADEC Chlorine Demand/Decay - Black Water Test Series #2										
Client ID	Lab ID	FP Dose	Free Residual	Free Demand	Total Residual	FP Temp.	FP Start	FP Take-Off	FP Time (H:M)	FP Time (Hr.)
Blackwater	BW-1-test2	12.00				12	6/23/06 12:33			
10 min			0.18	11.82	3.76	12		6/23/06 12:43	0:10	0.17
3-4 mg/L Total	added seawater		0.73	11.27	1.45	12		6/23/06 12:48	0:15	0.25
2:1			0.31	11.69	1.20	12		6/23/06 13:38	1:05	1.08
			0.00	12.00	0.75	12		6/23/06 20:50	8:17	8.28
			0.05	11.95	0.36	12		6/24/06 12:00	23:27	23.45
			0.04	11.96	0.06	12		6/24/06 14:22	25:49	25.82
			0.00	12.00	0.05	12		6/26/06 11:00	70:27	70.45
Blackwater	BW-2-test2	17.00				12	6/23/06 13:55			
10 min			0.30	16.70	7.90	12		6/23/06 14:06	0:11	0.18
8-10 mg/L	added seawater		0.95	16.05	1.78	12		6/23/06 14:10	0:15	0.25
4:1			0.25	16.75	1.35	12		6/23/06 15:23	1:28	1.47
			0.11	16.89	1.04	12		6/23/06 20:48	6:53	6.88
			0.10	16.90	0.73	12		6/24/06 12:04	22:09	22.15
			0.13	16.87	0.92	12		6/24/06 14:22	24:27	24.45
			0.10	16.90	0.18	12		6/26/06 11:16	69:21	69.35
			0.00	17.00	0.1			6/27/06 11:00	93:05	93.08
Blackwater	BW-3-test2	12.00				12	6/23/06 14:01			
10 min			0.14	11.86	3.20	12		6/23/06 14:10	0:09	0.15
3-4 mg/L	added seawater		1.56	10.44	1.40	12		6/23/06 14:15	0:14	0.23
2:1			0.18	11.82	1.07	12		6/23/06 15:28	1:27	1.45
			0.17	11.83	0.81	12		6/23/06 20:37	6:36	6.60
			0.17	11.83	0.32	12		6/24/06 12:08	22:07	22.12
			0.04	11.96	0.07	12		6/24/06 14:30	24:29	24.48
			0.00	12.00	0.04	12		6/26/06 23:16	81:15	81.25
Blackwater	BW-4-test2	18.00				12	6/23/06 16:27			
10 min			0.27	17.73	10.60	12		6/23/06 16:43	0:16	0.27
8-10 mg/L	added seawater		1.43	16.57	2.70	12		6/23/06 16:50	0:23	0.38
4:1			0.38	17.62	1.41	12		6/23/06 17:40	1:13	1.22
			0.12	17.88	1.09	12		6/24/06 20:43	28:16	28.27
			0.08	17.92	0.84	12		6/24/06 12:10	19:43	19.72
			0.08	17.92	0.38	12		6/25/06 14:37	46:10	46.17
			0.07	17.93	0.24	12		6/26/06 11:20	66:53	66.88
			0.10	17.90	0.11	12		6/27/06 11:05	90:38	90.63
Blackwater	BW-5-test2	10.00				12	6/23/06 15:28			
20 min			0.05	9.95	2.88	12		6/23/06 15:48	0:20	0.33
3-4 mg/L	added seawater		0.58	9.42	1.04	12		6/23/06 15:58	0:30	0.50
2:1			0.22	9.78	0.58	12		6/23/06 17:32	2:04	2.07
			0.11	9.89	0.52	12		6/23/06 20:25	4:57	4.95
			0.10	9.90	0.16	12		6/24/06 12:12	20:44	20.73
			0.00	10.00	0.02	12		6/24/06 14:42	23:14	23.23
			0.00	10.00	0.02	12		6/26/06 11:21	67:53	67.88
Blackwater	BW-6-test2	18.50				12	6/23/06 17:25			
20 min			0.24	18.26	10.20	12		6/23/06 17:35	0:10	0.17
8-10 mg/L	added seawater		0.93	17.57	2.00	12		6/23/06 17:39	0:14	0.23
4:1			0.15	18.35	1.01	12		6/23/06 19:26	2:01	2.02
			0.00	0.75	0.75	12		6/23/06 20:50	3:25	3.42
			0.06	0.56	0.56	12		6/24/06 12:27	19:02	19.03
			0.00	0.17	0.17	12		6/24/06 14:48	21:23	21.38
			0.00	0.17	0.29	12		6/26/06 11:35	66:10	66.17
			0.00	0.17	0.04	12		6/27/06 11:07	89:42	89.70
Blackwater	BW-7-test2	11.00				12	6/23/06 15:48			
20 min			0.08	10.92	4.16	12		6/23/06 16:08	0:20	0.33
3-4 mg/L	added seawater		0.92	10.08	1.20	12		6/23/06 16:18	0:30	0.50
2:1			0.30	10.70	0.93	12		6/23/06 16:46	0:58	0.97
			0.08	10.92	0.66	12		6/23/06 20:37	4:49	4.82
			0.00	11.00	0.14	12		6/24/06 12:23	20:35	20.58
			0.04	10.96	0.1	12		6/25/06 14:46	46:58	46.97
			0.04	10.96	0.06	12		6/26/06 11:37	67:49	67.82
Blackwater	BW-8-test2	18.50				12	6/23/06 15:22			
20 min			0.17	18.33	10.20	12		6/23/06 16:42	1:20	1.33
8-10 mg/L	added seawater		1.01	17.49	3.30	12		6/23/06 16:02	0:40	0.67
4:1			0.37	18.13	1.44	12		6/23/06 16:40	1:18	1.30
			0.17	18.33	1.02	12		6/23/06 20:42	5:20	5.33
			0.00	18.50	0.57	12		6/24/06 12:19	20:57	20.95
			0.11	18.39	0.33	12		6/24/06 14:52	23:30	23.50
			0.07	18.43	0.16	12		6/26/06 11:30	68:08	68.13
			0.05	18.45	0.08	12		6/27/06 11:12	91:50	91.83

ADEC Chlorine Demand/Decay - Black Water & Gray Water Blend Test Series #1										
Client ID	Lab ID	FP Dose	Free Residual	Free Demand	Total Residual	FP Temp.	FP Start	FP Take-Off	FP Time (H:M)	FP Time (Hr.)
BW/GW Mix	BW/GW-1-test1	10.50				12	6/23/06 17:40			
10 min			0.1	10.40	3.00	12		6/23/06 17:50	0:10	0.17
3-4 mg/L	added seawater		0.19	10.31	1.32	12		6/23/06 18:00	0:20	0.33
1:1			0.07	10.43	0.77	12		6/23/06 19:29	1:49	1.82
			0.00	10.50	0.00	12		6/24/06 13:00	19:20	19.33
			0.04	10.46	0.05	12		6/25/06 15:00	45:20	45.33
			0.00	10.50	0.02	12		6/26/06 11:47	66:07	66.12
BW/GW Mix	BW/GW-2-test1	20.00				12	6/24/06 9:31			
10 min			0.30	19.70	9.60	12		6/24/06 9:41	0:10	0.17
8-10 mg/L	added seawater		1.04	18.96	2.24	12		6/24/06 9:46	0:15	0.25
2:1			0.04	19.96	1.62	12		6/24/06 13:06	3:35	3.58
			0.08	19.92	0.64	12		6/25/06 15:04	29:33	29.55
			0.03	19.97	0.30	12		6/26/06 15:31	54:00	54.00
			0.04	19.96	0.2	12		6/27/06 10:02	72:31	72.52
BW/GW Mix	BW/GW-3-test1	10.60				12	6/23/06 19:27			
10 min			0.22	10.38	2.72	12		6/23/06 19:45	0:18	0.30
3-4 mg/L	added seawater		0.24	10.36	1.30	12		6/23/06 19:52	0:25	0.42
1:1			0.00	10.60	0.12	12		6/24/06 12:46	17:19	17.32
			0.00	10.60	0.03	12		6/25/06 15:09	43:42	43.70
			0.00	10.60	0.00	12		6/26/06 11:53	64:26	64.43
						12				
BW/GW Mix	BW/GW-4-test1	20.00				12	6/23/06 20:17			
10 min			0.15	19.85	9.50	12		6/23/06 20:27	0:10	0.17
8-10 mg/L	added seawater		0.69	19.31	3.30	12		6/23/06 20:35	0:18	0.30
2:1			0.03	19.97	0.75	12		6/24/06 12:55	16:38	16.63
			0.02	19.98	0.55	12		6/25/06 15:13	42:56	42.93
			0.02	19.98	0.40	12		6/26/06 11:44	63:27	63.45
			0.03	19.97	0.11	12		6/27/06 10:20	86:03	86.05
BW/GW Mix	BW/GW-5-test1	11.50				12	6/23/06 17:09			
20 min			0.06	11.44	2.92	12		6/23/06 17:32	0:23	0.38
3-4 mg/L	added seawater		0.17	11.33	1.16	12		6/23/06 17:42	0:33	0.55
1:1			0.20	11.30	0.67	12		6/23/06 19:10	2:01	2.02
			0.00	11.50	0.06	12		6/24/06 12:42	19:33	19.55
			0.05	11.45	0.05	12		6/25/06 15:19	46:10	46.17
			0.03	11.47	0	12		6/26/06 12:08	66:59	66.98
BW/GW Mix	BW/GW-6-test1	21.00				12	6/23/06 17:14			
20 min			0.13	20.87	10.50	12		6/23/06 17:24	0:10	0.17
8-10 mg/L	added seawater		1.24	19.76	2.80	12		6/23/06 17:29	0:15	0.25
2:1			0.09	20.91	2.02	12		6/23/06 19:20	2:06	2.10
			0.00	21.00	0.73	12		6/24/06 12:51	19:37	19.62
			0.08	20.92	0.43	12		6/25/06 15:25	46:11	46.18
			0.10	20.90	0.23	12		6/26/06 11:53	66:39	66.65
			0.04	20.96	0.14	12		6/27/06 10:29	89:15	89.25
BW/GW Mix	BW/GW-7-test1	12.40				12	6/23/06 20:09			
20 min			0.14	12.26	3.16	12		6/23/06 20:19	0:10	0.17
3-4 mg/L	added seawater		0.18	12.22	1.24	12		6/23/06 20:25	0:16	0.27
1:1			0.00	12.40	0.13	12		6/24/06 12:38	16:29	16.48
			0.00	12.40	0.07	12		6/25/06 15:35	43:26	43.43
			0.00	12.40	0.17	12		6/26/06 12:01	63:52	63.87
						12				
BW/GW Mix	BW/GW-8-test1	20.50				12	6/23/06 19:44			
20 min			0.22	20.28	9.00	12		6/23/06 20:04	0:20	0.33
8-10 mg/L	added seawater		1.14	19.36	3.40	12		6/23/06 20:08	0:24	0.40
2:1			0.03	20.47	0.82	12		6/24/06 12:33	16:49	16.82
			0.05	20.45	0.39	12		6/25/06 15:30	43:46	43.77
			0.09	20.41	0.18	12		6/26/06 12:08	64:24	64.40
			0.00	20.50	0.05	12		6/27/06 10:39	86:55	86.92

ADEC Chlorine Demand/Decay - Black Water & Gray Water Blend Test Series #2										
Client ID	Lab ID	FP Dose	Free Residual	Free Demand	Total Residual	FP Temp.	FP Start	FP Take-Off	FP Time (H:M)	FP Time (Hr.)
BW/GW Mix	BW/GW-1-test2	10.50				12	6/24/06 10:37			
10 min			0.03	10.47	2.98	12		6/24/06 10:47	0:10	0.17
3-4 mg/L	added seawater		0.81	9.69	0.90	12		6/24/06 10:52	0:15	0.25
2:1			0.11	10.39	0.57	12		6/24/06 13:41	3:04	3.07
			0.05	10.45	0.02	12		6/25/06 15:41	29:04	29.07
			0.00	10.50	0.00	12		6/26/06 13:05	50:28	50.47
						12				
BW/GW Mix	BW/GW-2-test2	19.00				12	6/24/06 10:52			
10 min			0.15	18.85	8.30	12		6/24/06 11:02	0:10	0.17
8-10 mg/L	added seawater		1.08	17.92	1.80	12		6/24/06 11:09	0:17	0.28
4:1			0.03	18.97	0.90	12		6/24/06 13:41	2:49	2.82
			0.06	18.94	0.43	12		6/25/06 3:45	16:53	16.88
			0.05	18.95	0.22	12		6/26/06 13:11	50:19	50.32
			0.05	18.95	0.1	12		6/27/06 9:36	70:44	70.73
BW/GW Mix	BW/GW-3-test2	10.80				12	6/24/06 10:50			
10 min			0.2	10.60	3.10	12		6/24/06 11:00	0:10	0.17
3-4 mg/L	added seawater		0.74	10.06	0.90	12		6/24/06 11:04	0:14	0.23
2:1			0.02	10.78	0.52	12		6/24/06 13:37	2:47	2.78
			0.07	10.73	0.11	12		6/25/06 15:48	28:58	28.97
			0.00	10.80	0.00	12		6/26/06 13:15	50:25	50.42
						12				
BW/GW Mix	BW/GW-4-test2	20.00				12	6/24/06 11:07			
10 min			0.13	19.87	9.10	12		6/24/06 11:17	0:10	0.17
8-10 mg/L	added seawater		1.18	18.82	1.56	12		6/24/06 11:23	0:16	0.27
4:1			0.10	19.90	0.46	12		6/24/06 13:32	2:25	2.42
			0.10	19.90	0.46	12		6/25/06 3:55	16:48	16.80
			0.30	19.70	0.26	12		6/26/06 13:21	50:14	50.23
			0.05	19.95	0.15	12		6/27/06 9:47	70:40	70.67
BW/GW Mix	BW/GW-5-test2	12.40				12	6/24/06 9:47			
20 min			0.12	12.28	3.42	12		6/24/06 10:07	0:20	0.33
3-4 mg/L	added seawater		0.80	11.60	1.07	12		6/24/06 10:17	0:30	0.50
2:1			0.04	12.36	0.53	12		6/24/06 13:29	3:42	3.70
			0.08	12.32	0.06	12		6/25/06 15:57	30:10	30.17
			0.02	12.38	0.00	12		6/26/06 1:27	39:40	39.67
						12				
BW/GW Mix	BW/GW-6-test2	20.70				12	6/24/06 9:36			
20 min			0.19	20.51	8.40	12		6/24/06 9:56	0:20	0.33
8-10 mg/L	added seawater		0.97	19.73	1.50	12		6/24/06 10:02	0:26	0.43
4:1			0.02	20.68	0.86	12		6/24/06 13:21	3:45	3.75
			0.00	20.70	0.47	12		6/25/06 16:01	30:25	30.42
			0.01	20.69	0.10	12		6/26/06 1:35	39:59	39.98
			0.02	20.68	0.08	12		6/27/06 9:15	71:39	71.65
BW/GW Mix	BW/GW-7-test2	12.40				12	6/24/06 9:50			
20 min			0.11	12.29	3.02	12		6/24/06 10:10	0:20	0.33
3-4 mg/L	added seawater		0.6	11.80	1.02	12		6/24/06 10:17	0:27	0.45
2:1			0.01	12.39	0.46	12		6/24/06 13:25	3:35	3.58
			0.03	12.37	0.02	12		6/25/06 16:04	30:14	30.23
			0.00	12.40	0.00	12		6/26/06 13:38	51:48	51.80
						12				
BW/GW Mix	BW/GW-8-test2	20.50				12	6/24/06 11:33			
20 min			0.1	20.40	9.70	12		6/24/06 11:43	0:10	0.17
8-10 mg/L	added seawater		1.04	19.46	1.22	12		6/24/06 11:45	0:12	0.20
4:1			0.08	20.42	0.49	12		6/24/06 13:17	1:44	1.73
			0.08	20.42	0.49	12		6/25/06 4:08	16:35	16.58
			0.09	20.41	0.26	12		6/26/06 1:42	38:09	38.15
			0.08	20.42	0.14	12		6/27/06 9:50	70:17	70.28