Performance evaluation in land-based test facility

PureBallast 3.0

Advanced oxidation technology with two mechanical filter options, Hydac AutoFilt®RF10 and Boll & Kirch 6.18.3

AlfaWall AB

Final report

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The expert in **WATER ENVIRONMENTS**

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Abbreviations

Abbreviation	Description
AOT	Advanced oxidation technology
AVG	Average
BE	Biological efficacy
BWMS	Ballast water management system
CFU	Colony-forming units
CMFDA	Chloromethylfluorescein diacetate
DOC	Dissolved organic carbon
DNV	Det Norske Veritas
DPM	Disintegrations per minute
ETV	US-EPA, Environmental Technology Verification Program
FDA	Fluorescein diacetate
FR	Field replicate
IMO	International Maritime Organization
MEPC	Marine Environment Protection Committee
MM	Mineral materials
MPN	Most probable number
NTU	Nephelometric turbidity units
O&M	Operation and maintenance
POC	Particulate organic carbon
PSU	Practical salinity units
QAPP	Quality assurance project plan
SOP	Standard operating procedure
STD	Standard deviation
T0	Day 0 samples
T5	Day 5 samples
TSS	Total suspended solids
UV	Ultraviolet
UV-T	UV transmittance
UVI	UV intensity
WET	Whole effluent toxicity

1 Executive summary

DHI provides independent performance evaluation of ballast water management systems (BWMS) for the approval process. The purpose of the performance evaluation is to assure that BWMS approved by administrations are capable of meeting the ballast water discharge standard in Regulation D-2 /1/, also known as the IMO D-2 standard, in land-based and shipboard evaluations and do not cause unacceptable harm to the vessel, crew, environment or public health. The United States Coast Guard Standards for Living Organisms in Ships' Ballast Water Discharged in U.S. Waters /4/ (§151.2030) establish a ballast water discharge standard similar to the IMO D-2 standard. According to the U.S. Coast Guard, the test set-up in land-based test cycles of BWMS must operate as described in the ETV protocol /5/.

The objective of this project was to conduct a performance evaluation of the AlfaWall BWMS PureBallast 3.0 in a land-based test facility with the aim to meet the United States Coast Guard standards /4/ and the testing requirements in Resolution MEPC.174(58) /2/.

From October 2012 through June 2013, DHI conducted a land-based test of the AlfaWall BWMS PureBallast 3.0 with Det Norske Veritas (DNV) as classification society.

The basic treatment principles with PureBallast 3.0 BWMS are mechanical filtration and advanced oxidation technology (AOT) by ultra violet (UV) radiation. Mechanical filtration was only applied during ballast operations whereas disinfection in the AOT reactor was applied both during ballast and de-ballast operations.

A total of 14 biological efficacy (BE) test cycles and five operation and maintenance (O&M) test cycles were conducted. PureBallast 3.0 was operated independently by DHI staff during all BE and O&M test cycles. AlfaWall staff was present at the test facility during all BE test cycles. Seven BE test cycles were conducted with brackish water, and seven BE test cycles were conducted with marine water. The total ambient water volume processed during the five O&M test cycles exceeded 10,000 m^3. During land-based testing in October-November 2012, the mechanical filtration technology used in 11 of the BE test cycles was a Hydac AutoFilt® RF10 equipped with 50-µm mesh filter candles. During land-based testing in March, April and June 2013, the mechanical filtration technology used in three of the BE test cycles was a Boll & Kirch 6.18.3 equipped with 40-µm mesh filter candles.

PureBallast 3.0 was tested in salinities ranging from 17 to 19 PSU and from 32 to 36 PSU with water temperatures ranging from approx. 1 to 18°C. The concentrations of total suspended solids (TSS), particulate organic carbon (POC), dissolved organic carbon (DOC) and mineral materials (MM) were in accordance with the minimum water quality characteristics in the IMO G8 guidelines and the ETV protocol in all BE test cycles except for minor deviations. In two BE test cycles, the concentration of TSS in the inlet water was 49 mg/L (instead of >50 mg/L) and, in two BE test cycles, the concentration of DOC in the inlet water was 5.8 mg/L (instead of ≥6 mg/L).

The densities of viable organisms and the number of taxa and species identified in the inlet and control discharge water were in accordance with the IMO G8 guidelines and the ETV protocol in all test cycles. The average densities of viable organisms ≥50 µm ranged from approx. 170,000 to 600,000 organisms/m^3 in the inlet water, and from approx. 13,000 to 160,000 organisms/m^3 in the control discharge water. The average densities of viable organisms ≥10 and <50 µm determined by inverted microscopy varied from approx. 1,200 to 8,000 organisms/mL in the inlet water, and from approx. 260 to 4,000 organisms/mL in the control discharge water. Heterotrophic bacteria were present in concentrations from approx. 52,000 to approx. 650,000 CFU/mL in the inlet water and from approx. 107,000 to >200,000 CFU/mL in the control discharge water.

Table 1.1 summarizes the number of viable organisms in water treated with PureBallast 3.0 at discharge, where the viable organisms in the ≥10 and <50 µm size class were quantified by algal re-growth and addition of motile organisms without chlorophyll. DHI considers this quantification, which is also referred to as the most probable number of proliferating algae and addition of chloromethylfluorescein diacetate/fluorescein diacetate (CMFDA/FDA) stained motile organisms without chlorophyll, the best available technique to determine viable organisms in the ≥10 and <50 µm size class after UV treatment. Table 1.2 summarizes the numbers of viable organisms in the ≥10 and <50 µm size class obtained by microscopic counting after staining with CMFDA and FDA and the results of measurements of algal primary production.

Table 1.1 Average flow rates after filtration, UV-T, UVI during ballast operation and average numbers (three replicates) of viable organisms in treated water at discharge. Viable organisms ≥10 and <50 µm were quantified by the most probable number of proliferating algae and addition of CMFDA/FDA-stained motile organisms without chlorophyll. Test cycles were conducted with Hydac filter (H) or Boll & Kirch 6.18.3 filter (BK).

Test cycle	Average flow rate		UV-T (%)	UV-I (W/m^2)	Organisms ≥50 µm per m^3	Organisms ≥10 and <50 µm per mL Algal re-growth + CMFDA/FDA-stained motile organisms	Organisms <10 µm Enterococci (CFU/100 mL)	Organisms <10 µm *E. coli* (CFU/100 mL)	Organisms <10 µm *V. cholerae* (CFU/100 mL)
	Treated (m^3/h)	Control (m^3/h)							
B-1 (H)*	307	318	48	312	9.0	0.30	<1	<10	Absent
B-2 (H)*	311	318	48	310	10.3	0.57	<1	<10	Absent
B-3 (H)	301	318	53	486	2.7	0.18	<1	<10	Absent
B-4 (H)	296	318	53	484	1.7	<0.18	<1	<10	Absent
B-5 (H)	283	319	53	471	0	0.25	<1	<10	Absent
B-6 (H)	277	319	53	477	0.67	<0.18	1.3	<10	Absent
B-7 (BK)	306	316	54	487	8.3	3.0	<1	<10	Absent
M-1 (H)	300	318	56	421	0.33	0.66	<1	<10	Absent
M-2 (H)	301	316	57	470	1.0	<0.18	<1	<10	Absent
M-3 (H)	303	316	57	470	0.33	<0.18	<1	<10	Absent
M-4 (H)	280	318	58	459	0.33	<0.18	<1	<10	Absent
M-5 (H)	250	318	58	459	1.0	<0.18	<1	<10	Absent
M-6 (BK)**	317	321	55	425	14	83	<1	<10	Absent
M-7 (BK)	310	321	53	467	0.67	<0.18	15	<10	Absent
Require-ments	-	-	-	-	<10	<10	<100	<250	<1

* UV transmittance was 48%, which is outside the borders of the technology performance claim stated in Section 6.1
** Leakage of the bypass valve
UV-T UV transmittance
UV-I UV intensity
CFU Colony-forming units

Table 1.2 Average numbers (three replicates) of viable organisms ≥10 and <50 µm quantified by microscopic counting after staining with CMFDA and FDA and measurements of algal primary production. Test cycles were conducted with Hydac filter (H) or Boll & Kirch 6.18.3 filter (BK).

Test cycle	Organisms ≥10 and <50 µm	
	Microscopy after CMFDA/FDA staining (organisms/mL)	Primary production* (% decrease)
B-1 (H)**	19	100
B-2 (H)**	28	100
B-3 (H)	13	100
B-4 (H)	17	100
B-5 (H)	11	100
B-6 (H)	9.8	100
B-7 (BK)	49	100
M-1 (H)	42	100
M-2 (H)	65	100
M-3 (H)	59	100
M-4 (H)	51	100
M-5 (H)	36	100
M-6 (BK)***	283	99
M-7 (BK)	27	100

* Primary production is expressed as the percentage reduction of the primary production in inlet water samples

** UV transmittance was 48%, which is outside the borders of the technology performance claim stated in Section 6.1

*** Leakage of the bypass valve

Practical experience from previous land-based tests conducted by DHI indicates that UV-based BWMS are frequently unable to meet the ballast water discharge standard if the treatment performance of organisms ≥10 and <50 µm is evaluated solely on the basis of microscopy after staining with CMFDA and FDA. These stains react with non-specific esterases and intact stained cells fluoresce under the microscope. The unsuitability of the microscopic counting of CMFDA/FDA-stained cells for evaluation of UV effects can be explained biologically as follows: UV radiation causes damage to the cell DNA and prevents cell proliferation but the esterase enzyme activity and the cell membrane may stay intact for several days. Consequently, the total numbers of viable organisms ≥10 and <50 µm obtained by microscopic counting after CMFDA/FDA-staining, which exceeded the ballast water discharge standard, were disregarded in the evaluation. Algal re-growth determined as the MPN of proliferating algae and addition of CMFDA/FDA-stained motile organisms without chlorophyll was applied in this land-based test for the evaluation of treatment performance in relation to organisms ≥10 and <50 µm (data in Table 1.1). In the land-based test of PureBallast 3.0, the algal taxa and species capable of growing under the conditions applied in the algal re-growth assay represented 69-89% (brackish water test cycles) and 85-91% (marine test cycles) of the taxa and species identified in the inlet water.

The performance evaluation based on algal re-growth and addition of motile organisms without chlorophyll for the organisms ≥10 and <50 µm (Table 1.1) leads to the conclusion that the PureBallast 3.0 with the exception of test cycles B-2 and M-6 complied with the ballast water discharge standard in all test cycles. It is noted that test cycle B-2 was conducted with a UV transmittance outside the borders of the performance claim stated in Section 6.1. A leaking bypass valve may explain the unsuccessful result of test cycle M-6 (Appendix B; date: 2013.06.10).

2 Introduction

DHI is an independent, international consulting and research organisation established in Denmark and today represented in all regions of the world with a total of more than 1,000 employees. Our objectives are to advance technological development, governance and competence in the fields of water, environment and health. DHI works with governmental agencies and authorities, contractors, consultants and numerous industries.

DHI provides independent performance evaluation of ballast water management systems (BWMS) for the approval process. DHI has no involvement, intellectual or financial, in the mechanics, design or marketing of the products and technologies that are being evaluated. To ensure that DHI's tests are uncompromised by any real or perceived individual or team bias relative to test outcomes, DHI's test activities are subject to rigorous quality assurance (QA), quality control (QC) and documentation. DHI's quality management system is certified according to ISO 9001 by Det Norske Veritas (DNV). The certification is facilitated by the implementation of the DHI Business Management System.

For an application for final approval, the IMO International Convention for the Control and Management of Ships' Ballast Water and Sediments /1/ requires a performance evaluation of BWMS according to the principles laid down in Resolution MEPC.174(58) /2/, generally referred to as the IMO G8 guidelines, and, for systems that make use of active substances, also Resolution MEPC.169(57) /3/, generally referred to as the IMO G9 guidelines. The purpose of the performance evaluation is to assure that BWMS approved by administrations are capable of meeting the ballast water discharge standard in Regulation D-2 /1/, also known as the IMO D-2 standard, in land-based and shipboard evaluations and do not cause unacceptable harm to the vessel, crew, environment or public health. The United States Coast Guard Standards for Living Organisms in Ships' Ballast Water Discharged in U.S. Waters /4/ (§151.2030) establish a ballast water discharge standard similar to the IMO D-2 standard. According to the U.S. Coast Guard, the test set-up in land-based test cycles of BWMS must operate as described in the ETV protocol /5/.

The objective of this project was to conduct a performance evaluation of the AlfaWall BWMS PureBallast 3.0 in a land-based test facility with the aim to meet the United States Coast Guard standards /4/ and the testing requirements in Resolution MEPC.174(58) /2/. DHI obtained acceptance as sub-laboratory to the Independent Laboratory with DNV as the accepted facility by Letter of Acceptance from United States Coast Guard (U.S. Coast Guard) dated 11 June 2013. During the land-based testing with PureBallast 3.0 from October 2012 to June 2013, DHI was not recognized as an Independent Laboratory according to the U.S. Coast Guard standards, and DHI shall not be responsible if this fact is taken into account in the evaluation by the U.S. Coast Guard.

The acting classification society for the land-based test of PureBallast 3.0 was DNV.

This report describes a series of 14 land-based test cycles conducted by DHI from October 2012 to June 2013 with PureBallast 3.0. Two different mechanical filters were used during these 14 test cycles. In 11 of the test cycles, a Hydac AutoFilt®RF10 filter equipped with 50-µm mesh filter candles was used. The last three test cycles were conducted with a Boll & Kirch 6.18.3 filter equipped with 40-µm mesh filter candles. The limited number of test cycles with the Boll & Kirch 6.18.3 filter was conducted as additional tests to the series of 11 test cycles. AlfaWall's intention with these additional test cycles is to achieve type approval for the use of either of the two filters with PureBallast 3.0 BWMS.

3 Classification society

The classification society appointed by the client for inspection and certification of the project is:

Det Norske Veritas A/S (DNV)
Veritasveien 1
NO-1363 Høvik
Norway

4 Client

The client requesting the performance evaluation is:

AlfaWall AB
Hans Stahles Väg 7
SE-147 80 Tumba
Sweden

The client is the manufacturer of the BWMS PureBallast 3.0.

5 Testing laboratory

DHI established a land-based test facility in Hundested, Denmark, in June 2010. A description of the test facility is available in the quality assurance project plan (QAPP) in Appendix A.

DHI Denmark was recognized as a sub-laboratory to the Independent Laboratory with DNV as the accepted test facility by Letter of Acceptance from U.S. Coast Guard dated 11 June 2013. DHI's Environmental Laboratory has an accreditation according to ISO 17025 which includes biological analyses related to performance evaluation of BWMS and ecotoxicological studies. Furthermore, the laboratory is authorized to carry out ecotoxicological studies in compliance with the OECD Principles of Good Laboratory Practice (GLP) (Appendix H).

DHI's Environmental Laboratory and staff normally analyse all samples collected during the performance evaluation of BWMS. If required, specialized chemical analyses of, e.g., active substances or disinfection by-products, are conducted by a subcontractor.

The performance evaluation of PureBallast 3.0 was conducted by DHI Denmark at the following facilities:

DHI Environmental Laboratory
Agern Allé 5
DK-2970 Hørsholm
Denmark

DHI Maritime Technology Evaluation Facility
Færgevejen 18
DK-3390 Hundested
Denmark

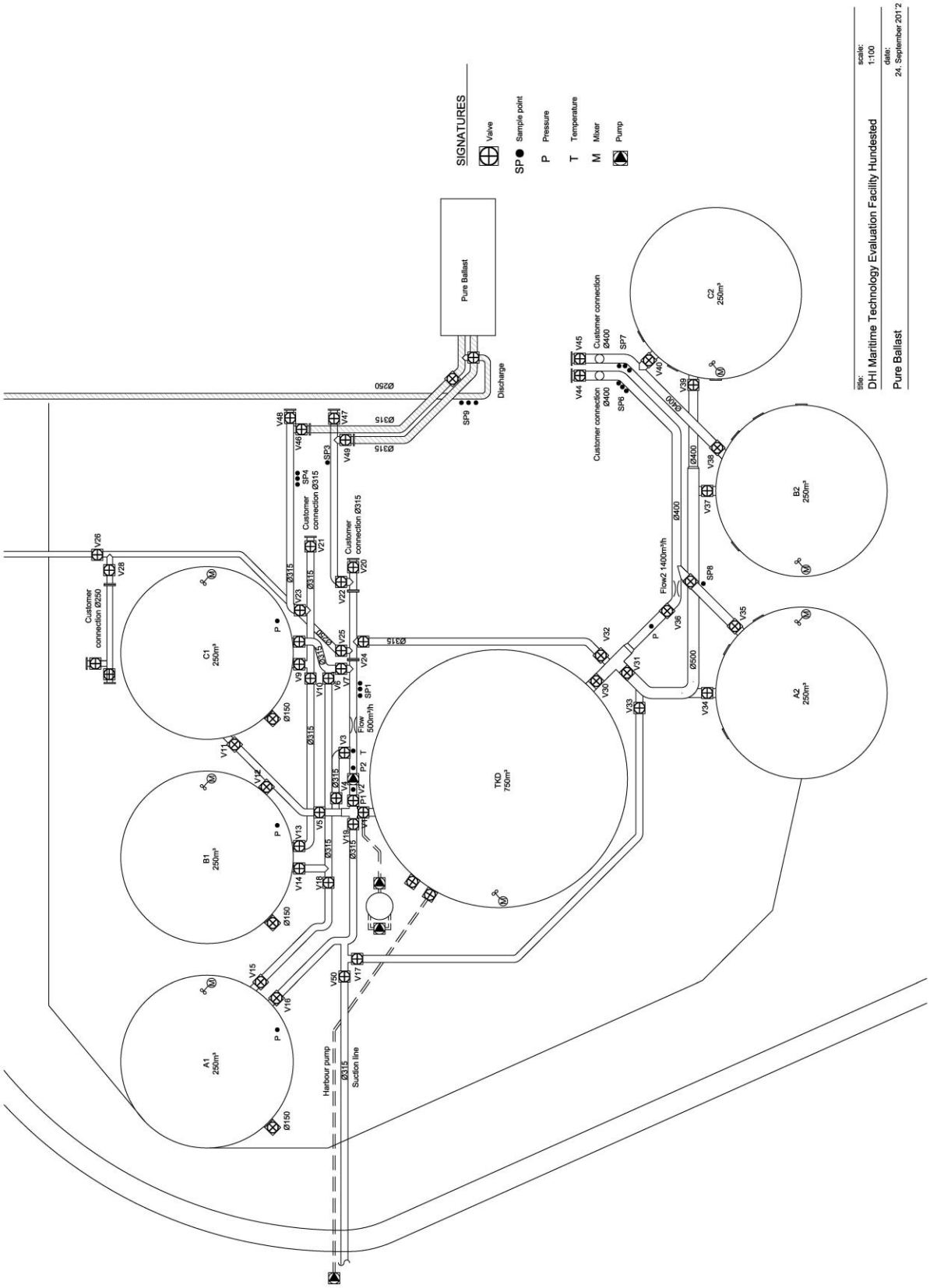

Figure 5.1 DHI Maritime Technology Evaluation Facility, Hundested, Denmark

6 Ballast water management system

The basic treatment principles with PureBallast 3.0 BWMS are mechanical filtration and advanced oxidation technology (AOT) by ultra violet (UV) radiation. Mechanical filtration was only applied during ballast operations whereas disinfection in the AOT reactor was applied both during ballast and de-ballast operations. The total rated capacity of the PureBallast 3.0 BWMS tested by DHI was 300 m^3/h. A technology and process description of PureBallast 3.0 was enclosed in Appendix B of the QAPP (Appendix A).

6.1 Performance claim and BWMS limitation

Before land-based testing was initiated, AlfaWall described a technology performance claim for PureBallast 3.0, which was included in Section 4.1 of the QAPP (Appendix A). This performance claim included a limitation regarding the treatment performance related to UV transmittance in the test water, and it was stated that, at total rated capacity, PureBallast 3.0 could be expected to achieve biological performance according to the ballast water discharge standard /1/, /4/ at a UV transmittance down to 50% (UV-T at 254 nm).

7 Experimental design

The PureBallast 3.0 performance evaluation involved physical and biological characterisation of water upon ballasting (inlet water) and comparison of organisms in control versus treated water immediately following treatment and at discharge after five days storage and second treatment. Biological characterisations supported comparison with the ballast water discharge standard /1/, /4/.

7.1 Trial period, installation and operation of PureBallast 3.0

A total of 14 biological efficacy (BE) test cycles and five operation and maintenance (O&M) test cycles were conducted throughout the test period. Seven BE test cycles were conducted in brackish water (B-1 to B-7), and seven BE test cycles were conducted in high saline marine water (M-1 to M-7). All O&M test cycles were conducted in brackish water.

During land-based testing in October-November 2012, the mechanical filtration technology used in the 11 test cycles was a Hydac AutoFilt® RF10 equipped with 50-µm mesh filter candles (in tables designated ‘Hydac’ or ‘H’).

A BE test cycle with PureBallast 3.0 and a Boll & Kirch 6.18.2 filter was conducted in November 2012 (the results of this test cycle are reported in Appendix F). AlfaWall decided not to continue testing with this filter model and, instead, the BE testing continued with the new filter model Boll & Kirch 6.18.3.

During land-based testing in March, April and June 2013, the mechanical filtration used in three test cycles was a Boll & Kirch 6.18.3 equipped with 40-µm mesh filter candles (in tables, designated ‘Boll & Kirch 6.18.3’ or ‘BK’).

Before initiating the BE test cycles, pilot testing was conducted during two weeks in September 2012. Pilot test cycles were conducted with brackish water at two different UV transmittance levels and two different types of filter candles were tested. A limited sampling and analysis programme was applied in the pilot test. The pilot test confirmed

that PureBallast 3.0 was installed correctly and was operating in accordance with the requirements of AlfaWall. Furthermore, the ability to achieve biological performance according to the ballast water discharge standard /1/, /4/ was confirmed during the pilot test. Finally, the pilot testing was used for training DHI staff in the independent operation of the BWMS.

AlfaWall decided not to conduct an actual commissioning test as outlined in the ETV protocol with a commissioning verification report.

PureBallast 3.0 was operated independently by DHI staff during all BE and O&M test cycles. AlfaWall staff was present at the test facility during all BE test cycles. AlfaWall's log on description of adjustments, service and maintenance actions related to the BWMS during the trial period is enclosed in Appendix B. Adjustment, service and maintenance actions carried out by AlfaWall staff were witnessed by DHI staff.

7.2 Biological efficacy verification testing

7.2.1 BWMS treatment process

The BE test cycles were conducted by use of the source tank (Tank D), control tank (Tank A1) and one retention tank per test cycle (Tank B1 or C1) (Figure 5.1).

During ballast operation, the treatment of the test water with PureBallast 3.0 involved the following steps:

1. A fraction of the test water contained in the source tank was pumped to in-line treatment in the BWMS and further to one of the retention tanks (treated water) until minimum 200 m^3 of water had been treated by the BWMS (mechanical filtration and advanced oxidation technology).
2. Another fraction of the same test water (minimum 200 m^3) was pumped directly into the control tank, by-passing the BWMS (control water). The control water served as a control of the BWMS performance.
3. Piping system and sample ports were cleaned (DHI SOP 30/1763).

PureBallast 3.0 had a total rated capacity of 300 m^3/h after the mechanical filter, i.e. the treatment of minimum 200 m^3 of test water took at least 40 minutes.

During ballasting, the flow, pressure, temperature, dissolved oxygen, pH, salinity, turbidity and water levels in the tanks were recorded automatically (DHI SOP 30/1764).

Samples were collected before and after first treatment by use of the relevant sample ports. Sampling was initiated when the flow rate had reached steady-state conditions, i.e. up to 5 minutes from the start of operation (DHI SOPs 30/1738 and 30/1762). The samples were labelled (DHI SOP 30/1750).

7.2.2 Storage of treated and untreated test water

Following the treatment of the test water in the BWMS, the treated water was stored in the retention tank for at least 5 days $\pm$ 4 hours. The same storage time was applied for the control water.

7.2.3 Second treatment and discharge of test water

1. Treated water contained in the retention tank was pumped through the BWMS for second treatment, after which it was discharged into the harbour (treated discharge water).
2. Control water contained in the control tank was discharged into the harbour (control discharge water).
3. The retention tanks, piping system and sample ports were cleaned (DHI SOP 30/1763).

During de-ballasting, the flow, pressure, water temperature, dissolved oxygen, pH, salinity, turbidity and water levels in the tanks were recorded automatically (DHI SOP 30/1764).

Samples of the treated discharge water were collected by use of the sampling ports on the BWMS discharge line whereas samples of the control discharge water were collected by use of sampling ports on the test facility discharge line. Isokinetic sampling methodology with fixed sample volumes was applied according to the principles described in MEPC.173(58) (G2) /6/.

7.2.4 Biological efficacy test cycles

An overview of dates, time periods, treated volumes, corresponding flow rates and the mechanical filters used for all 14 BE test cycles is presented in the table below.

Table 7.1 Details for inlet and discharge operations for biological efficacy test cycles. Test cycles were conducted with Hydac filter (H) or Boll & Kirch 6.18.3 filter (BK).

Test cycle	Type	Inlet				Discharge		
		Date & time	UV-T (%)	UV-I (W/m^2)	Treated volume and flow rate*	Date & time	Treated volume and flow rate	UV-I (W/m^2)
B-1 (H)	BWMS	2012.10.04 10:40-11:23	48	312	220 m^3 307 m^3/h	2012.10.09 08:51-09:29	201 m^3 317 m^3/h	362
	Control	2012.10.04 11:34-12:13		-	206 m^3 318 m^3/h	2012.10.09 11:07-11:44	196 m^3 319 m^3/h	-
B-2 (H)	BWMS	2012.10.04 12:49-13:29	48	310	210 m^3 311 m^3/h	2012.10.09 10:14-10:52	200 m^3 315 m^3/h	356
	Control	2012.10.04 11:34-12:13		-	206 m^3 318 m^3/h	2012.10.09 11:07-11:44	196 m^3 319 m^3/h	-
B-3 (H)	BWMS	2012.10.11 09:40-10:23	53	486	216 m^3 301 m^3/h	2012.10.16 08:28-09:06	200 m^3 315 m^3/h	528
	Control	2012.10.11 10:26-11:04		-	204 m^3 318 m^3/h	2012.10.16 11:00-11:36	191 m^3 318 m^3/h	-
B-4 (H)	BWMS	2012.10.11 11:57-12:39	53	484	207 m^3 296 m^3/h	2012.10.16 10:04-10:41	196 m^3 315 m^3/h	523
	Control	2012.10.11 10:26-11:04		-	204 m^3 318 m^3/h	2012.10.16 11:00-11:36	191 m^3 318 m^3/h	-
B-5 (H)	BWMS	2012.10.18 09:47-10:32	53	471	212 m^3 283 m^3/h	2012.10.23 09:07-09:44	194 m^3 316 m^3/h	507
	Control	2012.10.18 10:45-11:23		-	204 m^3 319 m^3/h	2012.10.23 11:09-11:46	197 m^3 320 m^3/h	-
B-6 (H)	BWMS	2012.10.18 12:08-12:54	53	477	212 m^3 277 m^3/h	2012.10.23 10:27-11:05	199 m^3 318 m^3/h	508
	Control	2012.10.18 10:45-11:23		-	204 m^3 319 m^3/h	2012.10.23 11:09-11:46	197 m^3 320 m^3/h	-

Test cycle	Type	Inlet				Discharge		
		Date & time	UV-T (%)	UV-I (W/m^2)	Treated volume and flow rate*	Date & time	Treated volume and flow rate	UV-I (W/m^2)
B-7 (BK)	BWMS	2013.03.08 10:07-10:48	54	487	209 m^3 306 m^3/h	2013.03.13 11:03-11:41	194 m^3 305 m^3/h	577
	Control	2013.03.08 10:58-11:39		-	214 m^3 316 m^3/h	2013.03.13 12:25-13:08	200 m^3 279 m^3/h	-
M-1 (H)	BWMS	2012.10.25 13:29-14:10	56	421	205 m^3 300 m^3/h	2012.10.30 09:41-10:16	189 m^3 317 m^3/h	464
	Control	2012.10.25 14:55-15:33		-	204 m^3 318 m^3/h	2012.10.30 12:02-12:36	181 m^3 319 m^3/h	-
M-2 (H)	BWMS	2012.11.01 12:04-12:46	57	470	211 m^3 301 m^3/h	2012.11.06 08:40-09:16	195 m^3 316 m^3/h	495
	Control	2012.11.01 12:54-13:32		-	202 m^3 316 m^3/h	2012.11.06 10:58-11:33	186 m^3 319 m^3/h	-
M-3 (H)	BWMS	2012.11.01 14:01-14:42	57	470	207 m^3 303 m^3/h	2012.11.06 10:08-10:45	195 m^3 318 m^3/h	494
	Control	2012.11.01 12:54-13:32		-	202 m^3 316 m^3/h	2012.11.06 10:58-11:33	186 m^3 319 m^3/h	-
M-4 (H)	BWMS	2012.11.08 10:08-10:54	58	459	215 m^3 280 m^3/h	2012.11.13 08:48-09:24	199 m^3 318 m^3/h	500
	Control	2012.11.08 11:10-11:48		-	205 m^3 318 m^3/h	2012.11.13 11:19-11:56	196 m^3 318 m^3/h	-
M-5 (H)	BWMS	2012.11.08 12:41-13:31	58	459	208 m^3 250 m^3/h	2012.11.13 10:34-11:11	195 m^3 317 m^3/h	491
	Control	2012.11.08 11:10-11:48		-	205 m^3 318 m^3/h	2012.11.13 11:19-11:56	196 m^3 318 m^3/h	-
M-6 (BK)	BWMS	2013.04.04 10:34-11:14	55	425	211 m^3 317 m^3/h	2013.04.09 09:02-09:40	197 m^3 313 m^3/h	452
	Control	2013.04.04 11:36-12:14		-	206 m^3 321 m^3/h	2013.04.09 09:56-10:33	197 m^3 320 m^3/h	-
M-7 (BK)	BWMS	2013.06.13 09:54-10:35	53	467	212 m^3 310 m^3/h	2013.06.18 10:47-11:24	197 m^3 313 m^3/h	565
	Control	2013.06.13 12:10-12:49		-	208 m^3 321 m^3/h	2013.06.18 13:04-13:42	193 m^3 305 m^3/h	-

* Average flow rate after filtration based on time and treated volume logged during ballast operation at the DHI test facility

UV-T UV transmittance

UV-I UV intensity

Originally, BE test cycle M-6 with the Boll & Kirch 6.18.3 filter was initiated on 14 March 2013. However, when starting the ballast operation, it was observed that some of the elements dividing each filter candle in the middle were broken with the effect that these filter candles could not be cleaned during backwash. Therefore, the BE test cycle initiated on 14 March 2013 was abandoned and replaced by a new test cycle, which was conducted on 4 April 2013. The explanation from AlfaWall after consulting the filter manufacturer was that a production error was the likely cause of the fault in some of the filter elements (see Appendix B for more information).

For each BE test cycle, additional details regarding filter type, AOT reactor, addition of organisms, recordings of power consumption, UV intensities etc. are available in the data logging in Appendix C.

Samples for whole effluent toxicity (WET) testing were taken during test cycles B-5 and M-1, respectively. A separate report was prepared for the WET testing /7/.

7.3 Test water and challenge conditions in BE verification testing

Source water means the body of water, from which water is drawn for the land-based test. The IMO G8 guidelines /2/ and the ETV protocol /5/ describe three distinct water types that may be applied in the land-based test:

- Fresh water (salinity <1 PSU)
- Brackish water (salinity 10-20 PSU)
- Marine water (salinity >32-36 PSU)

The BE test cycles with PureBallast 3.0 were performed with brackish and marine water.

For BE test cycles with brackish water, the source water was collected immediately south of the pier adjacent to the test facility (DHI SOP 30/1735); under normal conditions, the natural salinity of the source water is 15-20 PSU.

For BE test cycles with marine water, the source water was collected immediately south of the pier adjacent to the test facility (DHI SOP 30/1735), and brine was added to achieve the required salinity (DHI SOP 30/1737).

7.3.1 Test water – water quality characteristics

Test water (equivalent to the term challenge water /4/, /5/) means the inlet water as contained in the source tank immediately prior to treatment. In land-based tests, source water may be adjusted to achieve the required challenge conditions. The test water was adjusted to meet the water quality parameters in Table 7.2.

Table 7.2 Minimum water quality characteristics according to the IMO G8 guidelines /2/ and, in parentheses, the ETV protocol /5/

Parameter	Test water		
	Fresh <3 (<1) PSU	Brackish 3-32 (10-20) PSU	Marine >32 (28-36) PSU
Dissolved organic carbon (DOC)	>5 (≥6) mg/L	>5 (≥6) mg/L	>1 (≥6) mg/L
Particulate organic carbon (POC)	>5 (≥4) mg/L	>5 (≥4) mg/L	>1 (≥4) mg/L
Total suspended solid (TSS) Mineral materials (MM) ≥ 20 mg/L	>50 (≥24) mg/L	>50 (≥24) mg/L	>1 (≥24) mg/L

If necessary to obtain the stated water quality parameters, the concentrations of dissolved organic carbon (DOC), particulate organic carbon (POC) and mineral materials (MM) were increased by additions of lignin sulphonate (DOC), starch (POC) and kaolin clay (MM) (DHI SOP 30/1737).

7.3.2 Test water – biological organism conditions

The test water was prepared to meet the densities of live organisms in Table 7.3.

Table 7.3 Minimum criteria for densities of live organisms in the test water according to the IMO G8 guidelines /2/ and the ETV protocol /5/

Organism size class	Total concentration	Diversity
≥50 µm	10^5 organisms/m^3	5 species across 3 phyla
≥10 µm and <50 µm	10^3 organisms/mL	5 species across 3 phyla
<10 µm	10^4/mL as culturable aerobic heterotrophic bacteria	Not applicable

If necessary to obtain the stated minimum criteria, the densities of live organisms were increased by addition of harvested indigenous organisms and/or cultured species (DHI SOP 30/1734). Addition of harvested and/or cultured species was recorded in the data logging in Appendix C. Heterotrophic bacteria were present in the test water in densities exceeding the minimum criteria described in Table 7.3.

The minimum densities of live organisms in the control discharge water are presented in Table 7.4.

Table 7.4 Minimum criteria for densities of live organisms in the control discharge water according to the IMO G8 guidelines /2/ and the ETV protocol /5/

Organism size class	Total concentration
≥ 50 µm	100 organisms/m^3
≥10 µm and < 50 µm	100 organisms/mL
<10 µm	5×10^2/mL as culturable aerobic heterotrophic bacteria

7.4 Operation and maintenance testing

Five O&M test cycles were conducted with PureBallast 3.0. The O&M test cycles were conducted in ballast operation mode with mechanical filtration and disinfection in the AOT reactor. The O&M test cycles were conducted with ambient water conditions. An overview of the dates, time periods, treated volumes, average flow rates and the mechanical filter used in the five O&M test cycles is presented in the table below.

Table 7.5 Details for operation and maintenance (O&M) test cycles

Test cycle	Date	Time	Volume	Average flow rate*	Filter
O&M-1	2012.10.12	08:51-15:26	2,048 m^3	314 m^3/h	Hydac
O&M-2	2012.10.19	06:53-13:45	2,031 m^3	297 m^3/h	Hydac
O&M-3	2012.10.24	09:59-16:42	2,110 m^3	316 m^3/h	Hydac
O&M-4	2012.10.31	07:58-15:51**	2,046 m^3	318 m^3/h	Hydac
O&M-5	2012.11.06	11:47-18:10	2,036 m^3	318 m^3/h	Hydac

* Average flow rate logged during ballast operation by flow meter in piping before PureBallast 3.0 (inlet to mechanical filter)

** O&M-4 was paused due to power loss as a result of test facility generator failures (see Appendix D)

The total water volume processed during the five O&M test cycles exceeded 10,000 m^3. The PureBallast 3.0 BWMS caused no mechanical failures or alarms during O&M testing.

For each O&M test cycle, additional details regarding filter type, AOT reactor, recordings of power consumption, UV intensities etc. are available in the data logging in Appendix D.

8 Sampling and analyses in BE verification testing

8.1 Sample overview

Table 8.1 Overview of sampling and purpose of samples

Parameter	Inlet water to BWMS and control tank	Treated water on day 0 (after first treatment)	Treated discharge water (after second treatment)	Control discharge water	Sample collection	Sample volume
Ballast and de-ballast operations						
Volume	×	×	×	×	Continuous	Online
Pressure	×	×	×	×	Continuous	Online
Flow	×	×	×	×	Continuous	Online
Other parameters*	×	×	×	×	Continuous	Online
Water quality conditions						
Temperature, salinity, turbidity, pH, dissolved oxygen	×	×	×	×	Continuous	Online
TSS, DOC***, POC*** and UV-T****	×	×	×	×	Discrete grab (3 replicates; start, middle, end)	Approx. 0.5 L
Concentrations of viable organisms						
Viable organisms ≥50 µm/m^3	×	×	×	×	Discrete (3 replicates; time integrated)	Inlet: 20 L After 1st treatment and during discharge: 1 m^3
Viable organisms ≥10 and <50 µm/mL	×	×	×	×	Discrete 3 replicates; each representing approx. ⅓ of the operation period)	Approx. 10 L
Viable organisms <10 µm/mL	×	×	×	×	Discrete grab (3 replicates; start, middle, end)	Approx. 0.5 L
Whole effluent toxicity (WET)	-	-	×*****	×****	Discrete (time integrated)	Approx. 25 L

* Operational parameters to ensure that the systems have been operated correctly and in accordance with the Operation and Maintenance manual
*** Measured in inlet and discharge samples
**** UV transmittance at 254 nm, 1 cm, measured in inlet samples
***** Only in BE test cycles B-5 and M-1

Flow-integrated samples were collected. The samples were stored in thermo boxes with cooler bricks in the dark from the time of collection until handling of the samples at the DHI Environmental Laboratory.

8.2 Inlet water and treated water after first treatment

Table 8.2 Sampling and analysis of inlet water to BWMS and control tank

Parameter	DHI SOP	Laboratory
Organisms ≥50 µm	30/1700	DHI
Organisms ≥10 µm and <50 µm		
Microscopy	30/1701	DHI
Primary production (algae)	30/1702	DHI
Re-growth assay (algae)	30/1704	DHI
Organisms <10 µm		
Heterotrophic aerobic bacteria	30/1706	DHI
E. coli and enterococci	30/1708	DHI
Physical/chemical properties		
Temperature, pH, O_2, salinity and turbidity	30/1764	DHI
TSS, DOC and POC	30/1768 + 30/1769	DHI
UV transmittance at 254 nm, 1 cm	30/1770	DHI

Table 8.3 Sampling and analysis of treated water after 1st treatment

Parameter	DHI SOP	Laboratory
Organisms ≥50 µm	30/1700	DHI
Organisms ≥10 µm and <50 µm		
Primary production (algae)	30/1702	DHI
Organisms <10 µm		
Heterotrophic aerobic bacteria	30/1706	DHI
Physical/chemical properties		
TSS	30/1768	DHI
Temperature, pH, O_2, salinity and turbidity	30/1764	DHI

8.3 Treated discharge water and control discharge water

Table 8.4 Sampling and analysis of treated discharge water after 2nd treatment

Parameter	DHI SOP	Laboratory
Organisms ≥50 µm	30/1700	DHI
Organisms ≥10 µm and <50 µm		
Microscopy	30/1701	DHI
Primary production (algae)	30/1702	DHI
Re-growth assay (algae)	30/1704	DHI
Organisms <10 µm		
Heterotrophic aerobic bacteria (only test cycles M-6 and M-7)	30/1706	DHI
Vibrio cholerae	30/1707	DHI
E. coli and enterococci	30/1708	DHI
Physical/chemical properties		
Temperature, pH, O_2, salinity and turbidity	30/1764	DHI
TSS, DOC and POC	30/1768 + 30/1769	DHI
Whole effluent toxicity (WET) (only test cycles B-5 and M-1)	30/326 (ISO/TC 147/SC 5 N 708 Draft) + 30/305 (ISO 10523) + 30/364 (OECD 212)	DHI

Table 8.5 Sampling and analysis of control discharge water

Parameter	DHI SOP	Laboratory
Organisms ≥50 µm	30/1700	DHI
Organisms ≥10 µm and <50 µm		
Microscopy	30/1701	DHI
Primary production (algae)	30/1702	DHI
Re-growth assay (algae)	30/1704	DHI
Organisms <10 µm		
Heterotrophic aerobic bacteria	30/1706	DHI
Vibrio cholerae	30/1707	DHI
E. coli and enterococci	30/1708	DHI
Physical/chemical properties		
Temperature, pH, O2, salinity and turbidity	30/1764	DHI
TSS, DOC and POC	30/1768 + 30/1769	DHI
Whole effluent toxicity (WET) (only test cycles B-5 and M-1)	30/326 (ISO/TC 147/SC 5 N 708 Draft) + 30/305 (ISO 10523) + 30/364 (OECD 212)	DHI

8.4 Analyses

8.4.1 Physical/chemical analyses

The following physical/chemical analyses were conducted (DHI SOPs 30/1764 and 30/1770):

- pH
- Turbidity
- Dissolved oxygen
- Ballast system pressure
- Ballast system flow rates
- UV transmittance at 254 nm, 1 cm
- Water volume in retention tanks

8.4.2 Organism size class ≥50 µm

The concentrations of live organisms ≥50 µm in minimum dimension were determined by use of a stereo microscope and a counting chamber (DHI SOP 30/1700). Viable organisms were enumerated by use of standard movement and response stimuli technique. The viable organisms were characterized according to broad taxonomic groups such as crustaceans (e.g. copepods), molluscs, rotifers, nematodes, etc.

For treated discharge samples, the total sample volume of each of the three field replicates (3 × 1 m^3 concentrated samples) was analysed.

8.4.3 Organism size class ≥10 µm and <50 µm

The concentrations of organisms and the presence of taxonomic groups in the inlet water were determined by inverted microscopy (DHI SOP 30/1701). Inverted microscopy was also used to determine the taxonomic groups of algae capable of growing under the conditions applied in the algal re-growth assay.

The numbers of viable organisms ≥10 µm and <50 µm in minimum dimension were determined by use of three different methods:

1. Microscopic counting after staining with chloromethylfluorescein diacetate (CMFDA) and fluorescein diacetate (FDA) (recommended in the ETV protocol /5/)
2. Most probable number of proliferating algae and addition of CMFDA/FDA stained motile organisms without chlorophyll
3. Measurement of algal primary production

Microscopic counting after staining with CMFDA and FDA

CMFDA and FDA were added to a subsample and, after incubation, the subsample was examined by use of a microscope under epifluorescence. Organisms labelled by either CMFDA or FDA were considered viable as described in DHI SOP 30/1701.

Most probable number of proliferating algae and addition of CMFDA/FDA-stained motile organisms without chlorophyll

a) Viable algae were quantified by measuring the most probable number (MPN) of proliferating algae in an algal re-growth assay. Growth under the conditions applied in the assay has been confirmed for 80% of the algal taxa and species in the inlet water (historical data obtained by DHI in test cycles conducted from 2011). The algal re-growth assay includes planktonic algae without reference to size and, thus, it is not limited to the ≥10 µm and <50 µm size class. A dilution series was prepared by

adding aliquots of subsample to test tubes with liquid medium. The test tubes were incubated for 14 days in light at ambient temperature. The concentrations of viable algae in the inlet water, control discharge water and treated discharge water were determined by measuring of the fluorescence in the test tubes before and after incubation (DHI SOP 30/1704). The MPN obtained after 14 days of incubation was recorded.

b) CMFDA/FDA-stained motile organisms without chlorophyll enumerated by microscopy (DHI SOP 30/1701) were recorded as a separate group.
c) The final result from this method was obtained by addition of the MPN and the number of CMFDA/FDA stained motile organisms without chlorophyll.

Algal primary production

The algal primary production was determined by measuring the ^{14}C fixed by photosynthesis. The algal primary production assay includes planktonic algae without reference to size, and, thus, it is not limited to the ≥10 µm and <50 µm size class. For each field replicate, $NaH^{14}CO_3$ (2 µCi) was added to two subsamples. These subsamples were incubated for approx. 75 min under light from a light panel at ambient temperature. After incubation, the samples were filtered onto Whatman GF/D filters. The filters were transferred to glass vials, and acid was added directly to the filters to release $^{14}CO_2$. The ^{14}C activity remaining in the algae on the filters after acidification was quantified by liquid scintillation counting according to DHI SOP 30/1702.

8.4.4 Organism size class <10 µm (bacteria)

The concentrations of heterotrophic aerobic bacteria were determined according to ISO 6222 (DHI SOP 30/1706). *E. coli* and enterococci were analysed (DHI SOP 30/1708). *Vibrio cholerae* was analysed according to ISO 21872 (DHI SOP 30/1707).

9 Results from biological efficacy test cycles

9.1 Inlet and control discharge water

9.1.1 Physical-chemical parameters

For all 14 BE test cycles, the physical-chemical conditions of inlet and control discharge water are summarized in Table 9.1 and Table 9.2. Detailed data on TSS, POC, DOC, MM and UV transmittance are available in Appendix E. Detailed online measurement data are available in the data logging in Appendix C.

Table 9.1 Inlet and control discharge water. Average concentrations (three replicates) of total suspended solids (TSS), particulate organic carbon (POC), dissolved organic carbon (DOC), mineral materials (MM) and average measurements of UV transmittance (UV-T). Test cycles were conducted with Hydac filter (H) or Boll & Kirch 6.18.3 filter (BK).

Test cycle	Sample	TSS (mg/L)	POC (mg/L)	DOC (mg/L)	MM (mg/L)*	UV-T (%)
B-1 and B-2 (H)	Inlet	49	6.7	10	42	48
	Control discharge	3.3	0.65	8.1	2.6	-
B-3 and B-4 (H)	Inlet	62	6.8	5.8	56	53
	Control discharge	5.8	0.54	5.4	5.3	-
B-5 and B-6 (H)	Inlet	60	7.1	6.5	53	53
	Control discharge	2.8	1.2	5.5	1.5	-
B-7 (BK)	Inlet	58	8.1	6.5	50	54/77**
	Control discharge	8.0	0.77	6.2	7.4	-
M-1 (H)	Inlet	42	6.3	8.2	36	56
	Control discharge	2.3	0.66	6.8	1.6	-
M-2 and M-3 (H)	Inlet	46	7.8	7.3	39	57
	Control discharge	3.4	1.0	6.4	2.5	-
M-4 and M-5 (H)	Inlet	49	8.2	7.3	41	58
	Control discharge	12	0.65	5.4	11	-
M-6 (BK)	Inlet	51	7.7	8.0	43	55/72**
	Control discharge	11	1.2	5.7	9.4	-
M-7 (BK)	Inlet	62	8.1	6.0	54	53/79**
	Control discharge	n.d.***	3.8	5.9	n.d.***	-
Require-ments	Fresh water and brackish water (inlet)****	>50 / ≥24	>5 / ≥4	>5 / ≥6	- / ≥20	-
	Marine water (inlet)****	>1 / ≥24	>1 / ≥4	>1 / ≥6	- / ≥20	-

* MM determined as the difference between TSS and POC as described in Section 5.4.6.1 of the ETV protocol
** Filtered
*** n.d., not determined (measured value of 0.33 mg TSS/L was considered incorrect)
**** Minimum water quality characteristics according to the IMO G8 guidelines /2/ and the ETV protocol /5/

Table 9.2 Inlet and control discharge water. Average measurements of dissolved oxygen, pH, salinity, temperature and turbidity. Test cycles were conducted with Hydac filter (H) or Boll & Kirch 6.18.3 filter (BK).

Test cycle	Sample	Oxygen (%)	pH	Salinity (PSU)	Temp. (°C)	Turbidity (NTU)
B-1 and B-2 (H)	Inlet control	101	8.1	17	13	26
	Control discharge	61	7.6	17	12	0.46
B-3 and B-4 (H)	Inlet control	101	8.2	18	10	33
	Control discharge	73	7.8	18	9.7	5.2
B-5 and B-6 (H)	Inlet control	99	8.2	19	10	41
	Control discharge	83	7.9	19	11	-*
B-7 (BK)	Inlet control	106	8.0	18	1.4	30
	Control discharge	98	7.9	18	0.83	6.2
M-1 (H)	Inlet control	99	8.0	34	10	22
	Control discharge	63	7.6	34	8.0	2.7
M-2 and M-3 (H)	Inlet control	93	8.0	32	7.0	25
	Control discharge	66	7.6	32	7.1	2.8
M-4 and M-5 (H)	Inlet control	91	7.9	36	7.7	24
	Control discharge	63	7.5	36	8.0	4.2
M-6 (BK)	Inlet control	117	7.8	33	3.3	23
	Control discharge	100	7.6	33	4.9	5.1
M-7 (BK)	Inlet control	99	8.1	34	18	34
	Control discharge	47	7.5	34	18	1.1
Require-ments	Fresh water**	-	-	<3 / <1	-	-
	Brackish water**	-	-	3-32 / 10-20	-	-
	Marine water**	-	-	>32 / 28-36	-	-

* Turbidity probe data logging error
** Minimum water quality characteristics according to the IMO G8 guidelines /2/ and the ETV protocol /5/
PSU Practical salinity units
NTU Nephelometric turbidity units

The concentrations of TSS, POC, DOC and MM were in accordance with the minimum water quality characteristics in the IMO G8 guidelines and the ETV protocol (Table 7.2) in all test cycles except for test cycles B-1 and B-2, in which the TSS concentration in the inlet was 49 mg/L (instead of >50 mg/L), and test cycles B-3 and B-4, in which the DOC concentration in the inlet was 5.8 mg/L (instead of ≥6 mg/L). These differences are considered negligible and without influence on the results. The measured salinities were within the salinity ranges prescribed by the IMO G8 guidelines and the ETV protocol.

9.1.2 Biological parameters

The densities of viable organisms in the inlet and control discharge water were in accordance with the IMO G8 guidelines and the ETV protocol (as described in Section 7.3.2) in all test cycles. Detailed data from the biological efficacy analyses are available in Appendix E.

9.1.2.1 Organism size class ≥50 µm

The average densities of viable organisms ≥50 µm in the inlet water ranged from approx. 240,000 to 600,000 organisms/m^3 in the brackish water test cycles and from approx. 170,000 to 250,000 organisms/m^3 in the marine water test cycles (Table 9.3). In the

control discharge water, the average densities of viable organisms ranged from approx. 40,000 to 160,000 organisms/m^3 in the brackish water test cycles and from approx. 13,000 to 60,000 organisms/m^3 in the marine water test cycles.

In the inlet water, the majority of the organisms ≥50 µm were identified as belonging to groups of crustaceans (copepods, nauplii, artemia), rotifers and to some extent molluscs. In each test cycle, the diversity of organisms ≥50 µm was in accordance with the recommendation of five different species divided between three phyla (as described in Section 7.3.2).

A complete taxonomic overview of the phyla and species identified in inlet and control discharge water samples in each of the 14 BE test cycles is available in Appendix E, Table E.7. The numeric distributions of organisms ≥50 µm in the inlet water samples according to taxonomic groups are available in Appendix E, Tables E.8-E.16.

Table 9.3 Inlet and control discharge water. Total sample volumes and average concentrations of viable organisms in the size class ≥50 µm. Average of nine or six replicates in inlet water and average of three replicates in control discharge water. Test cycles were conducted with Hydac filter (H) or Boll & Kirch 6.18.3 filter (BK).

Test cycle	Sample	Total sample volume (m^3)	Organisms/m^3
B-1 and B-2 (H)	Inlet	0.180	243,672
	Control discharge	3.0	62,217
B-3 and B-4 (H)	Inlet	0.180	598,982
	Control discharge	3.0	157,065
B-5 and B-6 (H)	Inlet	0.180	333,520
	Control discharge	3.0	42,134
B-7 (BK)	Inlet	0.120	332,567
	Control discharge	3.0	52,036
M-1 (H)	Inlet	0.120	168,553
	Control discharge	3.0	48,907
M-2 and M-3 (H)	Inlet	0.180	187,007
	Control discharge	3.0	13,283
M-4 and M-5 (H)	Inlet	0.180	232,600
	Control discharge	3.0	60,757
M-6 (BK)	Inlet	0.120	250,608
	Control discharge	3.0	50,875
M-7 (BK)	Inlet	0.120	244,611
	Control discharge	3.0	19,864
Require-ments	Inlet*	-	≥100,000
	Control discharge*	≥3	≥100

* Minimum criteria for live organism densities according to the IMO G8 guidelines /2/ and the ETV protocol /5/

9.1.2.2 Organism size class ≥10 and <50 µm

The average densities of viable organisms ≥10 and <50 µm in the inlet water determined by inverted microscopy varied from approx. 1,300 to 3,600 organisms/mL in the brackish water test cycles and from approx. 1,200 to 8,000 organisms/mL in the marine water test cycles (Table 9.4). In the control discharge water, the average densities of viable

organisms ranged from approx. 390 to 1,200 organisms/mL in the brackish water test cycles and from approx. 260 to 4,000 organisms/mL in the marine water test cycles.

In test cycle M-1, an increase of organisms ≥10 and <50 µm was observed during the five days in the control tank. Most likely, this increase was due to growth of ciliates during the five days' holding time. The majority of organisms observed in the control discharge water were ciliates of approx. 10 µm in minimum dimension.

As determined by the algal re-growth assay, the average densities of organisms in the inlet water with re-growth potential ranged from approx. 6,700 to >16,000 organisms/mL in the brackish water test cycles and from approx. 3,100 to 14,000 organisms/mL in the marine water test cycles. Determined by the algal re-growth assay, the average densities of organisms in the control discharge water ranged from approx. 1,400 to >1,600 organisms/mL in the brackish water test cycles and from approx. 320 to 1,400 organisms/mL in the marine water test cycles.

The algal taxa and species capable of growing under the conditions applied in the algal re-growth assay represented 69-89% (brackish water test cycles) and 85-91% (marine water test cycles) of the identified algae in the inlet water. An overview of the algal taxa and species identified in inlet water in the BE test cycles, and their ability to grow under the conditions in the re-growth assay is available in Appendix E, Table E.20.

Table 9.4 Inlet and control discharge water. Average concentrations (three replicates) of viable organisms in the size class ≥10 µm and <50 µm by microscopic counting and MPN together with measurements of primary production. Test cycles were conducted with Hydac filter (H) or Boll & Kirch 6.18.3 filter (BK).

Test cycle	Sample	Microscopy (organisms/mL)	Algal re-growth (organisms/mL)	Algal re-growth (%)**	Primary production (DPM)
B-1 and B-2 (H)	Inlet	1,334	>16,000	88	4,927
	Control discharge	572	>1,600		253
B-3 and B-4 (H)	Inlet	2,970	>16,000	77	8,415
	Control discharge	464	>1,600		682
B-5 and B-6 (H)	Inlet	2,232	16,000	69	7,271
	Control discharge	391	1,373		567
B-7 (BK)	Inlet	3,586	6,667	89	7,695
	Control discharge	1,218	>1,600		1,177
M-1 (H)	Inlet	1,715	13,733	85	6,158
	Control discharge	4,022	1,147		869
M-2 and M-3 (H)	Inlet	1,508	3,133	85	3,263
	Control discharge	509	830		1,389
M-4 and M-5 (H)	Inlet	1,221	3,133	86	2,090
	Control discharge	600	1,373		913
M-6 (BK)	Inlet	8,040	7,067	89	2,990
	Control discharge	1,240	477		434
M-7 (BK)	Inlet	2,290	10,200	91	4,714
	Control discharge	257	317		140
Require-ments	Inlet*	≥1,000	-	-	-
	Control discharge*	≥100	-	-	-

* Minimum criteria for live organism densities according to the IMO G8 guidelines /2/ and the ETV protocol /5/

** Algal taxa and species confirmed able to grow under the conditions in the re-growth assay (percentage of the taxa and species identified in the inlet water of the respective test cycles; data from Appendix E, Table E.20).

DPM Disintegrations per minute

9.1.2.3 Organism size class <10 µm (bacteria)

The average densities of viable organisms <10 µm in the inlet and control discharge water are summarized in Table 9.5. In the inlet water, heterotrophic bacteria were present in concentrations from approx. 52,000 to 168,500 CFU/mL in the brackish water test cycles and from approx. 61,000 to approx. 650,000 CFU/mL in the marine water test cycles. In the control discharge water, heterotrophic bacteria were present in concentrations from approx. 107,000 to >200,000 CFU/mL in the brackish water test cycles and from approx. 140,000 to approx. >200,000 CFU/mL in the marine water test cycles.

Table 9.5 Inlet and control discharge water. Average bacterial concentrations (three replicates). Test cycles were conducted with Hydac filter (H) or Boll & Kirch 6.18.3 filter (BK).

Test cycle	Sample	Heterotrophic bacteria (CFU/mL)	Enterococci (CFU/100 mL)	*E. coli* (CFU/100 mL)	*Vibrio cholerae* (CFU/100 mL)
B-1 and B-2 (H)	Inlet	168,500	166	<10	-
	Control discharge	154,833	1.2	>24,200	Absent
B-3 and B-4 (H)	Inlet	98,867	243	<10	-
	Control discharge	>200,000	102	<10	Absent
B-5 and B-6 (H)	Inlet	52,350	660	<10	-
	Control discharge	>200,000	86	<10	Absent
B-7 (BK)	Inlet	83,783	24	701	-
	Control discharge	107,417	11	2,852	Absent
M-1 (H)	Inlet	115,400	526	<10	-
	Control discharge	>200,000	164	17	Absent
M-2 and M-3 (H)	Inlet	442,500	534	<10	-
	Control discharge	140,167	18	<10	Absent
M-4 and M-5 (H)	Inlet	273,333	>2,420	<10	-
	Control discharge	>200,000	1,248	<10	Absent
M-6 (BK)	Inlet	61,417	>2,420	<10	-
	Control discharge	179,750	328	<10	Absent
M-7 (BK)	Inlet	645,833	>2,420	<10	-
	Control discharge	181,333	20	<10	Absent
Require-ments	Inlet*	≥10,000/ ≥1,000	-	-	-
	Control discharge*	≥1,000/≥500	-	-	-

* Minimum criteria for live organism densities according to the IMO G8 guidelines /2/ and the ETV protocol /5/

CFU Colony-forming units

9.2 Treated water

9.2.1 Physical-chemical parameters

The physical-chemical conditions of the treated water for all 14 BE test cycles are summarized in Table 9.6 and Table 9.7. Detailed data on TSS, POC, DOC, MM and UV-T are available in Appendix E. Detailed online measurement data are available in the data logging in Appendix C.

Table 9.6 Treated water. Average concentrations (three replicates) of total suspended solids (TSS), particulate organic carbon (POC), dissolved organic carbon (DOC) and mineral materials (MM). Test cycles were conducted with Hydac filter (H) or Boll & Kirch 6.18.3 filter (BK).

Test cycle	Sample*	TSS (mg/L)	POC (mg/L)	DOC (mg/L)	MM (mg/L)**
B-1 (H)	Treated T0	50	-	-	-
	Treated discharge	9.0	0.84	8.2	8.2
B-2 (H)	Treated T0	50	-	-	-
	Treated discharge	11	0.61	8.3	10
B-3 (H)	Treated T0	60	-	-	-
	Treated discharge	13	0.71	5.7	12
B-4 (H)	Treated T0	59	-	-	-
	Treated discharge	13	0.69	5.6	13
B-5 (H)	Treated T0	58	-	-	-
	Treated discharge	14	1.5	5.6	12
B-6 (H)	Treated T0	59	-	-	-
	Treated discharge	15	1.4	5.7	13
B-7 (BK)	Treated T0	56	-	-	-
	Treated discharge	13	0.86	6.7	12
M-1 (H)	Treated T0	39	-	-	-
	Treated discharge	10	1.3	7.2	8.9
M-2 (H)	Treated T0	46	-	-	-
	Treated discharge	15	1.3	6.6	13
M-3 (H)	Treated T0	50	-	-	-
	Treated discharge	15	1.2	6.6	13
M-4 (H)	Treated T0	44	-	-	-
	Treated discharge	12	1.2	5.3	11
M-5 (H)	Treated T0	47	-	-	-
	Treated discharge	14	1.7	5.8	12
M-6 (BK)	Treated T0	51	-	-	-
	Treated discharge	17	1.6	6.1	15
M-7 (BK)	Treated T0	61	-	-	-
	Treated discharge	8.7	2.3	5.9	6.5

* Treated T0 samples were collected on day 0 after first treatment. Treated discharge samples were collected at discharge after second treatment

** MM determined as the difference between TSS and POC as described in Section 5.4.6.1 of the ETV protocol /5/

Table 9.7 Treated water. Average measurements of dissolved oxygen, pH, salinity, temperature and turbidity. Test cycles were conducted with Hydac filter (H) or Boll & Kirch 6.18.3 filter (BK).

Test cycle	Sample*	Oxygen (%)	pH	Salinity (PSU)	Temp. (°C)	Turbidity (NTU)
B-1 (H)	Inlet	102	8.1	17	13	26
	Treated T0	100	8.1	17	13	26
	Before treatment T5	60	7.6	17	12	8.2
	Treated discharge	61	7.5	17	12	7.9
B-2 (H)	Inlet	102	8.1	17	13	26
	Treated T0	100	8.1	17	13	25
	Before treatment T5	56	7.6	17	12	9.1
	Treated discharge	57	7.5	17	12	8.1
B-3 (H)	Inlet	101	8.1	18	10	35
	Treated T0	100	8.1	18	10	33
	Before treatment T5	71	7.8	-**	9.7	14
	Treated discharge	71	7.7	-**	9.8	12
B-4 (H)	Inlet	102	8.2	18	11	27
	Treated T0	100	8.1	18	11	33
	Before treatment T5	74	7.9	-**	9.8	15
	Treated discharge	75	7.8	18	9.9	12
B-5 (H)	Inlet	99	8.1	19	10	43
	Treated T0	99	8.0	19	10	37
	Before treatment T5	82	7.9	19	11	-*
	Treated discharge	83	7.8	19	11	11
B-6 (H)	Inlet	100	8.2	19	10	43
	Treated T0	100	8.1	19	11	32
	Before treatment T5	78	7.9	19	11	-*
	Treated discharge	79	7.8	19	11	11
B-7 (BK)	Inlet	106	7.9	18	1.4	30
	Treated T0	106	7.7	18	1.5	29
	Before treatment T5	102	8.0	18	0.69	10
	Treated discharge	101	7.7	18	0.71	10
M-1 (H)	Inlet	99	8.0	34	10	23
	Treated T0	98	7.9	34	10	22
	Before treatment T5	74	7.7	34	7.6	10
	Treated discharge	73	7.6	34	7.6	10
M-2 (H)	Inlet	93	8.0	32	7.0	25
	Treated T0	93	7.8	32	7.1	25
	Before treatment T5	76	7.7	32	6.8	11
	Treated discharge	75	7.5	32	6.8	11
M-3 (H)	Inlet	93	8.0	32	7.1	26
	Treated T0	93	7.8	32	7.1	22
	Before treatment T5	76	7.7	32	6.9	11
	Treated discharge	76	7.6	32	6.9	11

Test cycle	Sample*	Oxygen (%)	pH	Salinity (PSU)	Temp. (°C)	Turbidity (NTU)
M-4 (H)	Inlet	91	7.9	36	7.7	25
	Treated T0	91	7.7	36	7.8	25
	Before treatment T5	67	7.5	36	7.8	11
	Treated discharge	68	7.4	36	7.8	10
M-5 (H)	Inlet	92	7.9	36	7.9	25
	Treated T0	92	7.8	36	7.9	28
	Before treatment T5	69	7.6	36	7.9	10
	Treated discharge	69	7.4	36	8.0	11
M-6 (BK)	Inlet	118	7.8	33	3.2	22
	Treated T0	118	7.9	33	3.3	22
	Before treatment T5	99	7.5	33	4.4	12
	Treated discharge	101	7.6	33	4.6	13
M-7 (BK)	Inlet	101	8.1	34	18	35
	Treated T0	101	8.0	34	18	33
	Before treatment T5	61	7.7	34	17	7.9
	Treated discharge	62	7.6	34	17	7.9

* Treated T0 samples were collected on day 0 after first treatment. Before treatment T5 samples were collected on day 5 prior to second treatment. Treated discharge samples were collected at discharge after second treatment
** Probe logging error
PSU Practical salinity units
NTU Nephelometric turbidity units

9.2.2 Biological parameters

9.2.2.1 Organism size class ≥50 µm

The average numbers of viable organisms ≥50 µm in their minimum dimension in the treated water are summarized in Table 9.8. The numbers of viable organisms ≥50 µm immediately after first treatment ranged from approx. 600 to approx. 11,000 organisms/m^3 in the brackish water test cycles and from approx. 50 to 1,800 organisms/m^3 in the marine water test cycles (Treated T0 samples in Table 9.8).

For **PureBallast 3.0 with Hydac AutoFilt® RF10 filter**, the numbers of viable organisms ≥50 µm at discharge were 9.0; 10.3; 2.7; 1.7; 0 and 0.67 organisms/ m^3 in the brackish water test cycles B1-B6 and 0.33; 1.0; 0.33; 0.33 and 1.0 organisms/ m^3 in the marine water test cycles M1–M5 (Treated discharge samples in Table 9.8). In test cycles B-1 and B-2, the UV transmittance was 48% (Table 9.1), which is outside the borders of the technology performance claim stated in Section 6.1.

For **PureBallast 3.0 with Boll & Kirch 6.18.3 filter**, the numbers of viable organisms ≥50 µm at discharge were 8.3 organisms/ m^3 in the brackish water test cycle B-7 and 14 and 0.67 organisms/ m^3, respectively, in the marine water test cycles M-6 and M-7 (Treated discharge samples in Table 9.8). Test cycle M-6 resulted in a high number of viable organisms (14 per m^3) compared with the other marine water test cycles. Leakage of the bypass valve V212-31 was observed and repaired after test cycle M-6 (Appendix B; date: 2013.06.10).

Table 9.8 Treated water. Total sample volumes and average numbers (three replicates) of viable organisms in the size class ≥50 µm.

Test cycle	Sample*	Total sample volume (m^3)	Organisms/m^3	Filter
B-1**	Treated T0	3	9,400	Hydac
	Treated discharge	3	9.0	Hydac
B-2**	Treated T0	3	11,111	Hydac
	Treated discharge	3	10.3	Hydac
B-3	Treated T0	3	2,932	Hydac
	Treated discharge	3	2.7	Hydac
B-4	Treated T0	3	2,682	Hydac
	Treated discharge	3	1.7	Hydac
B-5	Treated T0	3	598	Hydac
	Treated discharge	3	0	Hydac
B-6	Treated T0	3	1,716	Hydac
	Treated discharge	3	0.67	Hydac
B-7	Treated T0	3	3,772	Boll & Kirch 6.18.3
	Treated discharge	3	8.3	Boll & Kirch 6.18.3
M-1	Treated T0	3	1,764	Hydac
	Treated discharge	3	0.33	Hydac
M-2	Treated T0	3	518	Hydac
	Treated discharge	3	1.0	Hydac
M-3	Treated T0	3	379	Hydac
	Treated discharge	3	0.33	Hydac
M-4	Treated T0	3	50	Hydac
	Treated discharge	3	0.33	Hydac
M-5	Treated T0	3	76	Hydac
	Treated discharge	3	1.0	Hydac
M-6***	Treated T0	3	552	Boll & Kirch 6.18.3
	Treated discharge	3	14	Boll & Kirch 6.18.3
M-7	Treated T0	3	1,009	Boll & Kirch 6.18.3
	Treated discharge	3	0.67	Boll & Kirch 6.18.3
Requirements	Treated discharge	≥3	<10	-

* Treated T0 samples were collected on day 0 after first treatment. Treated discharge samples were collected at discharge after second treatment. The whole treated discharge sample after second treatment was counted

** UV transmittance was 48%, which is outside the borders of the technology performance claim stated in Section 6.1

*** Leakage of the bypass valve

9.2.2.2 Organism size class ≥10 and <50 µm

Table 9.9 summarizes the concentrations of viable organisms ≥10 and <50 µm in the treated water based on three different evaluation methodologies. Measurements of primary production showed that the decrease of algal photosynthesis ranged from 77 to 96% immediately after first treatment. The decrease in primary production in the treated discharge water after the second treatment ranged from 99 to 100%.

The quantitative evaluation of the performance after the second treatment at discharge was based on (i) microscopic counting after staining with CMFDA and FDA and (ii) most probable number of proliferating algae and addition of CMFDA/FDA-stained motile organisms without chlorophyll.

Microscopic counting after staining with CMFDA and FDA

For **PureBallast 3.0 with Hydac AutoFilt® RF10 filter**, the numbers of CMFDA/FDA-stained organisms ≥10 and <50 µm at discharge were 19; 28; 13; 17; 11 and 9.8 organisms/mL in the brackish water test cycles B-1 to B-6 and 42; 65; 59; 51 and 36 organisms/mL in the marine water test cycles M-1 to M-5 (Treated discharge samples in Table 9.9). In test cycles B-1 and B-2, the UV transmittance was 48% (Table 9.1), which is outside the borders of the technology performance claim stated in Section 4.1.

For **PureBallast 3.0 with Boll & Kirch 6.18.3 filter**, the numbers of CMFDA/FDA-stained organisms ≥10 and <50 µm at discharge were 49 organisms/mL in the brackish water test cycle B-7 and 283 and 27 organisms/mL, respectively, in the marine water test cycles M-6 and M-7 (Treated discharge samples in Table 9.9). Test cycle M-6 resulted in a high number of viable organisms (283 per mL) compared with the other marine water test cycles. Leakage of the bypass valve V212-31 was observed and repaired after test cycle M-6 (Appendix B; date: 2013.06.10).

A supplemental study was conducted with treated test water to examine the time-dependent 'die-away' of fluorescent cells after staining with CMFDA and FDA (Appendix G).

Most probable number of proliferating algae and addition of CMFDA/FDA-stained motile organisms without chlorophyll

For **PureBallast 3.0 with Hydac AutoFilt® RF10 filter**, the total numbers of the MPN obtained in the algal re-growth assay and the CMFDA/FDA-stained motile organisms without chlorophyll at discharge were 0.30; 0.57; 0.18; <0.18; 0.25 and <0.18 organisms/mL in the brackish water test cycles B-1 to B-6 and 0.66; <0.18; <0.18; <0.18 and <0.18 organisms/mL in the marine water test cycles M-1 to M-5 (Treated discharge samples in Table 7.9).

For **PureBallast 3.0 with Boll & Kirch 6.18.3 filter**, the total numbers of the MPN obtained in the algal re-growth assay and the CMFDA/FDA-stained motile organisms without chlorophyll at discharge were 3.0 organisms/mL in the brackish water test cycle B-7 and 83 and <0.18 organisms/mL, respectively, in the marine water test cycles M-6 and M-7 (Treated discharge samples in Table 9.9). Test cycle M-6 resulted in a high number of viable organisms (83 per mL) compared with the other marine water test cycles, which may be explained by the bypass valve leakage mentioned above.

Table 9.9 Treated water. Average numbers (three replicates) of viable organisms in the size class ≥10 µm and <50 µm and measurements of primary production. Test cycles were conducted with Hydac filter (H) or Boll & Kirch 6.18.3 filter (BK).

Test cycle	Sample*	Microscopy after CMFDA/FDA staining (organisms/mL)		Algal re-growth + CMFDA/FDA-stained motile organisms without chlorophyll (organisms/mL)	Primary production***	
		Total number	Motile without chlorophyll**		DPM	% decrease
B-1 (H)****	Treated T0	-	-	-	881	82
	Treated discharge	19	0.03	0.30	0	100
B-2 (H)****	Treated T0	-	-	-	840	83
	Treated discharge	28	0	0.57	0	100
B-3 (H)	Treated T0	-	-	-	418	95
	Treated discharge	13	0	0.18	1.2	100
B-4 (H)	Treated T0	-	-	-	400	95
	Treated discharge	17	0	<0.18	0	100
B-5 (H)	Treated T0	-	-	-	299	96
	Treated discharge	11	0.07	0.25	0	100
B-6 (H)	Treated T0	-	-	-	323	96
	Treated discharge	9.8	0	<0.18	0	100
B-7 (BK)	Treated T0	-	-	-	661	91
	Treated discharge	49	0	3.0	2.8	100
M-1 (H)	Treated T0	-	-	-	665	89
	Treated discharge	42	0.48	0.66	1.8	100
M-2 (H)	Treated T0	-	-	-	547	83
	Treated discharge	65	0	<0.18	2.7	100
M-3 (H)	Treated T0	-	-	-	537	84
	Treated discharge	59	0	<0.18	0.93	100
M-4 (H)	Treated T0	-	-	-	378	82
	Treated discharge	51	0	<0.18	0	100
M-5 (H)	Treated T0	-	-	-	357	83
	Treated discharge	36	0	<0.18	3.5	100
M-6 (BK)*****	Treated T0	-	-	-	688	77
	Treated discharge	283	0	83	24	99
M-7 (BK)	Treated T0	-	-	-	602	87
	Treated discharge	27	0	<0.18	2.6	100
Requirements	Treated discharge	<10	-	<10	-	

* Treated T0 samples were collected on day 0 after first treatment. Treated discharge samples were collected at discharge after second treatment

** The concentrations of motile organisms without chlorophyll are included in the total number of organisms

*** Primary production is expressed by the measured DPM (disintegrations per minute) and as the percentage reduction of the primary production in inlet water samples

**** UV transmittance was 48%, which is outside the borders of the technology performance claim stated in Section 6.1

***** Leakage of the bypass valve

9.2.2.3 Organism size class <10 µm (bacteria)

In the treated discharge water the contents of *E. coli* and enterococci were consistently below the ballast water discharge standard of <100 CFU/mL and <250 CFU/mL, respectively. *Vibrio cholerae* was not identified in any of the test cycles (Table 9.10).

Table 9.10 Treated water. Average bacterial concentrations (three replicates). Test cycles were conducted with Hydac filter (H) or Boll & Kirch 6.18.3 filter (BK).

Test cycle	Sample*	Heterotrophic bacteria (CFU/mL)	Enterococci (CFU/100 mL)	*E. coli* (CFU/100 mL)	*Vibrio cholerae* (CFU/100 mL)
B-1 (H)**	Treated T0	52	-	-	-
	Treated discharge	-	<1	<10	Absent
B-2 (H)**	Treated T0	36	-	-	-
	Treated discharge	-	<1	<10	Absent
B-3 (H)	Treated T0	99	-	-	-
	Treated discharge	-	<1	<10	Absent
B-4 (H)	Treated T0	101	-	-	-
	Treated discharge	-	<1	<10	Absent
B-5 (H)	Treated T0	47	-	-	-
	Treated discharge	-	<1	<10	Absent
B-6 (H)	Treated T0	30	-	-	-
	Treated discharge	-	1.3	<10	Absent
B-7 (BK)	Treated T0	23	-	-	-
	Treated discharge	-	<1	<10	Absent
M-1 (H)	Treated T0	60	-	-	-
	Treated discharge	-	<1	<10	Absent
M-2 (H)	Treated T0	102	-	-	-
	Treated discharge	-	<1	<10	Absent
M-3 (H)	Treated T0	45	-	-	-
	Treated discharge	-	<1	<10	Absent
M-4 (H)	Treated T0	191	-	-	-
	Treated discharge	-	<1	<10	Absent
M-5 (H)	Treated T0	68	-	-	-
	Treated discharge	-	<1	<10	Absent
M-6 (BK)	Treated T0	53	-	-	-
	Treated discharge	4.0	<1	<10	Absent
M-7 (BK)	Treated T0	368	-	-	-
	Treated discharge	122	15	<10	Absent
Require ments	Treated discharge	-	<100	<250	<1

* Treated T0 samples were collected on day 0 after first treatment. Treated discharge samples were collected at discharge after second treatment

** UV transmittance was 48%, which is outside the borders of the technology performance claim stated in Section 6.1

CFU Colony-forming units

10 Conclusion

PureBallast 3.0 successfully completed five O&M test cycles with a total processed water volume exceeding 10,000 m^3.

Table 10.1 summarizes the numbers of viable organisms in water treated by AlfaWall BWMS PureBallast 3.0 at discharge, in which the viable organisms in the ≥10 and <50 µm size class were quantified by algal re-growth and addition of motile organisms without chlorophyll. DHI considers this quantification, which is also referred to as the most probable number of proliferating algae and addition of CMFDA/FDA-stained motile organisms without chlorophyll, the best available technique to determine viable organisms in the ≥10 and <50 µm size class after UV treatment. Table 10.2 summarizes the numbers of viable organisms in the ≥10 and <50 µm size class obtained by microscopic counting after staining with CMFDA and FDA and the results of measurements of algal primary production.

Practical experience from previous land-based tests conducted by DHI shows that UV-based BWMS are most frequently unable to meet the ballast water discharge standard if the treatment performance of organisms ≥10 and <50 µm is evaluated solely on the basis of microscopy after staining with CMFDA and FDA. These stains react with non-specific esterases and intact stained cells fluoresce under the microscope. The unsuitability of the microscopic counting of CMFDA/FDA-stained cells for evaluation of UV effects can be explained biologically as follows: UV radiation causes damage of the cell DNA and prevents cell proliferation but the enzyme activity and the cell membrane may stay intact for several days (Appendix G includes data on a supplemental experiment). Consequently, the total numbers of viable organisms ≥10 and <50 µm obtained by microscopic counting after CMFDA/FDA-staining, which exceeded the ballast water discharge standard, were disregarded in the evaluation.

Algal re-growth determined as the most probable number of proliferating algae and addition of CMFDA/FDA-stained motile organisms without chlorophyll was applied in this land-based test for the evaluation of treatment performance in relation to organisms ≥10 and <50 µm (data in Table 10.1). In the land-based test of PureBallast 3.0, the algal taxa and species capable of growing under the conditions applied in the algal re-growth assay represented 69-89% (brackish water test cycles) and 85-91% (marine test cycles) of the taxa and species identified in the inlet water.

The performance evaluation based on algal re-growth and addition of motile organisms without chlorophyll for the organisms ≥10 and <50 µm (Table 10.1) leads to the conclusion that the PureBallast 3.0 with the exception of test cycles B-2 and M-6 complied with the ballast water discharge standard in all test cycles. It is noted that test cycle B-2 was conducted with a UV transmittance outside the borders of the performance claim stated in Section 6.1. A leaking bypass valve may explain the unsuccessful result of test cycle M-6 (Appendix B; date: 2013.06.10).

Table 10.1 Average numbers (three replicates) of viable organisms in treated water at discharge. Viable organisms ≥10 and <50 µm were quantified by the most probable number of proliferating algae and addition of CMFDA/FDA-stained motile organisms without chlorophyll. Test cycles were conducted with Hydac filter (H) or Boll & Kirch 6.18.3 filter (BK).

Test cycle	Organisms ≥50 µm per m^3	Organisms ≥10 and <50 µm per mL Algal re-growth + CMFDA/FDA-stained motile organisms	Organisms <10 µm Enterococci (CFU/100 mL)	Organisms <10 µm *E. coli* (CFU/100 mL)	Organisms <10 µm *V. cholerae* (CFU/100 mL)
B-1 (H)*	9.0	0.30	<1	<10	Absent
B-2 (H)*	10.3	0.57	<1	<10	Absent
B-3 (H)	2.7	0.18	<1	<10	Absent
B-4 (H)	1.7	<0.18	<1	<10	Absent
B-5 (H)	0	0.25	<1	<10	Absent
B-6 (H)	0.67	<0.18	1.3	<10	Absent
B-7 (BK)	8.3	3.0	<1	<10	Absent
M-1 (H)	0.33	0.66	<1	<10	Absent
M-2 (H)	1.0	<0.18	<1	<10	Absent
M-3 (H)	0.33	<0.18	<1	<10	Absent
M-4 (H)	0.33	<0.18	<1	<10	Absent
M-5 (H)	1.0	<0.18	<1	<10	Absent
M-6 (BK)**	14	83	<1	<10	Absent
M-7 (BK)	0.67	<0.18	15	<10	Absent
Require-ments	<10	<10	<100	<250	<1

* UV transmittance was 48%, which is outside the borders of the technology performance claim stated in Section 6.1

** Leakage of the bypass valve

CFU Colony-forming units

Table 10.2 Average numbers (three replicates) of viable organisms ≥10 and <50 µm quantified by microscopic counting after staining with CMFDA and FDA and measurements of algal primary production. Test cycles were conducted with Hydac filter (H) or Boll & Kirch 6.18.3 filter (BK).

Test cycle	Organisms ≥10 and <50 µm	
	Microscopy after CMFDA/FDA staining (organisms/mL)	Primary production* (% decrease)
B-1 (H)**	19	100
B-2 (H)**	28	100
B-3 (H)	13	100
B-4 (H)	17	100
B-5 (H)	11	100
B-6 (H)	9.8	100
B-7 (BK)	49	100
M-1 (H)	42	100
M-2 (H)	65	100
M-3 (H)	59	100
M-4 (H)	51	100
M-5 (H)	36	100
M-6 (BK)***	283	99
M-7 (BK)	27	100

* Primary production is expressed as the percentage reduction of the primary production in inlet water samples

** UV transmittance was 48%, which is outside the borders of the technology performance claim stated in Section 6.1

*** Leakage of the bypass valve

11 Quality assurance and quality control

The performance evaluation in land-based test facility of the PureBallast 3.0 BWMS was conducted in accordance with ISO 9001 by using the DHI Business Management System certified by DNV. The DHI Environmental Laboratory is accredited by DANAK, the Danish Accreditation and Metrology Fund, to perform ecotoxicological studies and analyses aiming at the performance evaluation of BWMS in accordance with ISO 17025. The performance evaluation also complied with the conditions included in the QMP, QAPP and SOPs (see Appendix H). Two amendments describing planned changes to the QAPP were made during the performance evaluation period. The QMP, QAPP and amendments are included in Appendix A.

The acting classification society for the land-based performance evaluation of PureBallast 3.0 was DNV. DNV conducted a review of the QAPP /8/. The overall conclusion in the DNV review of the QAPP is cited below:

> *"My impression is that the document is well written and strategies for sampling, testing, data handling are generally described in sufficient detail and are in compliance with the requirements for land based testing stated in the IMO Guidelines for Approval of Ballast Water Management Systems and the ETV protocol."*

DNV staff also conducted an onsite inspection during de-ballast operations of test cycles B-5 and B-6 on 23 October 2012. The inspection included the activities at the DHI test facility in Hundested and the analyses performed at the DHI Environmental Laboratory in Hørsholm, Denmark. The comments from the DNV review of the QAPP and the onsite inspection were addressed in the final version of the QAPP and in Amendment No. 1 to the QAPP.

12 References

/1/ IMO. International Convention for the Control and Management of Ships' Ballast Water and Sediments. London. International Maritime Organization, 2004.

/2/ MEPC. Guidelines for Approval of Ballast Water Management Systems (G8). Resolution MEPC.174(58). Adopted 10 October 2008.

/3/ MEPC. Procedure for Approval of Ballast Water Management Systems that make use of Active Substances (G9). MEPC.169(57). Adopted 4 April 2008.

/4/ U.S. Coast Guard. Standards for Living Organisms in Ships' Ballast Water Discharged in U.S. Waters. Federal Register, Vol. 77, No. 57, 23 March 2012.

/5/ U.S. Environmental Protection Agency, Environmental Technology Verification Program. Generic Protocol for the Verification of Ballast Water Treatment Technology (ETV protocol). EPA/600/R-10/146, September 2010.

/6/ Resolution MEPC.173(58). Adopted on 10 October 2008. Guidelines for approval of ballast water sampling (G2).

/7/ PureBallast 3.0 - Whole effluent toxicity (WET) tests. DHI. September, 2013.

/8/ DNV. Review of Quality Assurance Project Plan (QAPP) – for performance evaluation in land-based test facility of the PureBallast technology (AlfaWall AB). 2012.

APPENDIX A

QMP and QAPP with Amendments Nos. 1 and 2

Quality Management Plan

Performance Evaluation of Ballast Water Management Systems

DHI Denmark

Version 3.1

WATER • ENVIRONMENT • HEALTH

June 2012

Quality Management Plan

Performance Evaluation of Ballast Water Management Systems

DHI Denmark
Version 3.1

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Project	Project No.
Quality Management Plan Performance Evaluation of Ballast Water Management Systems DHI Denmark Version 3.1	
Author Gitte I. Petersen	Date 2012.06.20 Approved by Torben Madsen

Revision	Description	By	Checked	Approved	Date
3.1	QMP	G.P	TMA	TMA	20/6-12

Key words	Classification
	☐ Open ☐ Internal ☒ Proprietary

Distribution	No. of copies
Client Classification society DHI: /EAT	

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1 DEFINITIONS

Terms	Definitions
Active substance	Active substance means a chemical or an organism, including a virus or a fungus, that has a general or specific action on or against nonindigenous species
Ballast water management system (BWMS)	A system which processes ballast water to kill, render harmless or remove organisms. The BWMS includes all ballast water treatment equipment and all associated control and monitoring equipment
Classification society	Independent classification society that conducts formal verification of the procedures applied in performance evaluation of BWMS
Client	The manufacturer of a BWMS or related technology, or a party associated with such technologies, requesting a technology performance evaluation (sometimes referred to as vendor)
Guidelines	Guidelines means the IMO Guidelines for Approval of Ballast Water Management Systems (G8) (Reference /2/) and/or Procedure for Approval of Ballast Water Management Systems that Make Use of Active Substances (G9) (Reference /3/); in addition, performance evaluation of BWMS may also seek to verify compliance with the U.S. Coast Guard final rule (Reference /4/) and the ETV protocol (Reference /5/)
IMO convention	The International Convention for the Control and Management of Ship's Ballast Water and Sediments adopted by the International Maritime Organization (IMO) (Reference /1/)
International Maritime Organization (IMO)	United Nations specialized agency with responsibility for the safety and security of shipping and the prevention of marine pollution by ships
Land-based test	Land-based test means the performance evaluation of the BWMS conducted by use of the test facility and including operation of the BWMS in accordance with the guidelines
Pilot test	Pilot test means any experiment, including laboratory studies, used to test the BWMS with the purpose to identify and eliminate problems prior to initiation of formal performance evaluation meeting the guidelines
Quality assurance project plan (QAPP)	Project-specific technical document reflecting the implementation of quality assurance and quality control activities, including specifics of the BWMS to be tested, the testing organisation, and other conditions affecting the actual design and implementation of the required tests and evaluations Note: The DHI Business Management System applies quality assurance plan as the equivalent term for the QAPP
Quality management plan (QMP)	Generic standard operating procedure within the DHI Business Management System describing the project management and quality control management structure
Services	When used in this QMP the term 'services' has the meaning described in section 3
Shipboard test	Shipboard test means the performance evaluation of the BWMS installed on-board a vessel conducted in accordance with the guidelines
Standard operating procedure (SOP)	Document describing the procedures or characteristics for analyses, operations or tests Note: In-house methods may be used in the absence of a recognized standard, if they are commonly accepted for testing of BWMS or scientifically documented

U.S. Coast Guard	The U.S. Coast Guard is an organisation with the United States Department of Homeland Security. The Coast Guard is amending its regulations on ballast water management and engineering equipment by establishing a standard for the allowable concentration of living organisms in ships' ballast water discharged in waters of the United States and by establishing an approval process for BWMS

2 INTRODUCTION

The International Maritime Organization (IMO) has adopted the International Convention for the Control and Management of Ships' Ballast Water and Sediments /1/ to reduce the risk of spreading of harmful aquatic organisms and pathogens released with ballast water.

The IMO convention requires that all ships comply with specified water quality requirements (D2) before ballast water is released into the environment.

The performance evaluation of ballast water management systems (BWMS) aims at documenting compliance with the requirements stated in international guidelines, e.g.:

- Guidelines for Approval of Ballast Water Management Systems (G8) /2/
- Procedure for Approval of Ballast Water Management Systems that Make Use of Active Substances (G9) /3/.

DHI provides services in relation to performance evaluation of maritime technologies and particularly BWMS within the DHI Ballast Water Centre which includes land-based test facilities and laboratories in Denmark and Singapore. The land-based test facility in Denmark (Hundested) is known as the DHI Maritime Technology Evaluation Facility (hereafter referred to as the "test facility").

The DHI Ballast Water Centre is organized with a Ballast Water Facility Board including two members from the management in DHI Denmark and two members from the management in DHI Singapore. The object of the Board is to coordinate the development and marketing of services related to the performance evaluation of BWMS within the DHI Group.

The quality management plan (QMP) is a generic standard operating procedure within the DHI Business Management System.

3 SERVICES

The QMP covers the services provided by DHI Ballast Water Centre at the facilities below:

DHI
Agern Allé 5
DK-2970 Hørsholm
Denmark

and

DHI Maritime Technology Evaluation Facility
Færgevejen 18
DK-3390 Hundested
Denmark

The services include:

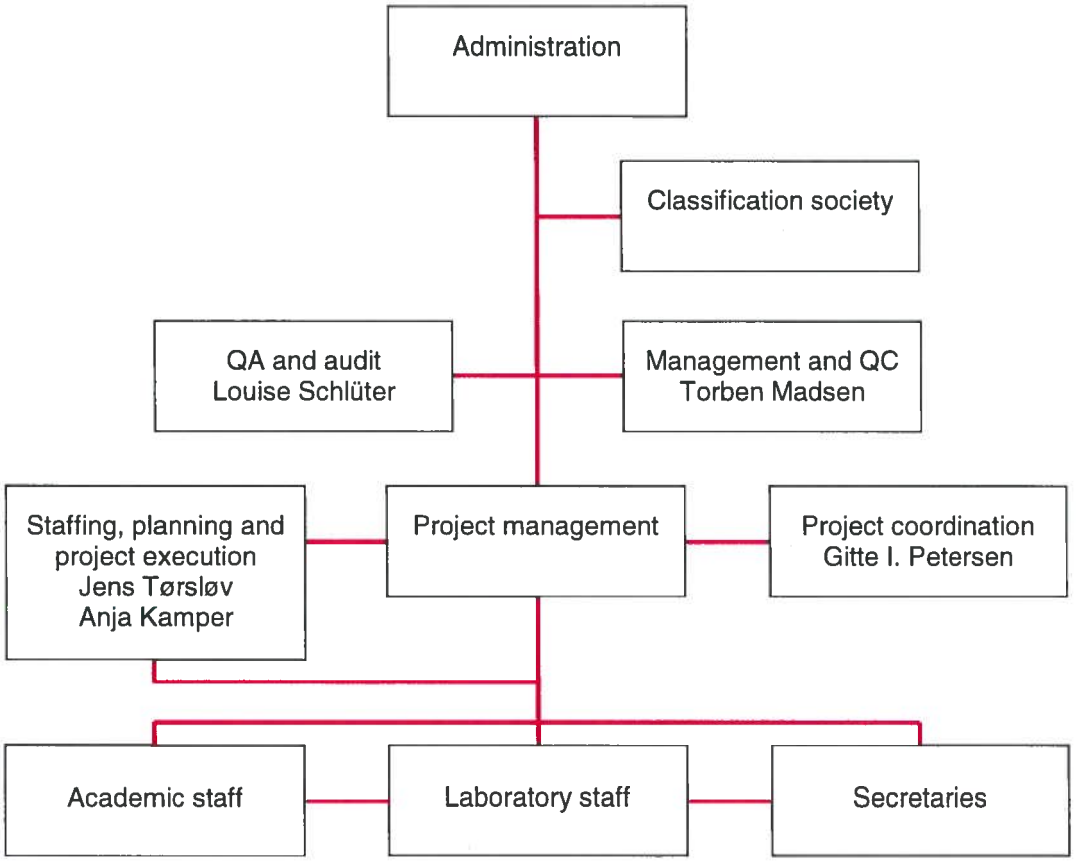
- Pilot-tests of BWMS, or ballast water treatment equipment, including laboratory studies, to identify and eliminate problems prior to initiation of formal performance evaluation meeting the guidelines
- Land-based tests of BWMS, or ballast water treatment equipment, conducted at the test facility and aiming at formal performance evaluation meeting the guidelines (e.g. type approval)
- Shipboard tests of BWMS, or ballast water treatment equipment, conducted on board vessels on which the technology is installed and aiming at formal performance evaluation meeting the guidelines (e.g. type approval).

The above activities are collectively referred to as the "services" whereas individual activities are referred to as "projects".

The aim of the services is to provide independent, third party documentation for the performance of maritime technologies. High quality of the services is ensured through extensive quality management and use of skilled staff.

4 ORGANISATION

The project organisation is illustrated below.



4.1 Quality assurance

Senior biologist Louise Schlüter (Ph.D.) is assigned by DHI's Quality Assurance (QA) Unit as internal auditor.

4.2 Management and quality control

Head of department Torben Madsen (Ph.D.) is quality supervisor for all projects (described in the section on Services) and has the overall responsibility for the services under DHI Ballast Water Centre, Denmark. This includes the following tasks:

- Member of the Ballast Water Test Facility Board for DHI Ballast Water Centre
- Overall responsibility for the test facility and the environmental laboratory including safe conditions of work and decisions on investments and maintenance expenses
- Negotiation of contracts with clients
- Appointment of project managers and staff responsible for quality control (QC) of individual data (data-level QC) and maintenance of staff experience records (allocation of projects managers for specific projects is the responsibility of the head of projects)
- Maintenance of the QMP with updated versions as appropriate
- Maintenance of generic standards that can serve as formats for drafting the quality assurance project plan (QAPP) and approval of the methods applied in land-based and shipboard tests
- Quality control of the QAPP, standard operating procedures (SOPs) and all project proposals, deliverables and reports

- Documentation in relation to
  - Staff training and experience
  - Facilities and their maintenance
  - Records of complaints

4.3 Project coordination

Business area manager Gitte I. Petersen (Ph.D.) is responsible for the coordination, timely execution and the overall scientific quality of the services. This includes the following tasks:

- Business development and marketing
- Co-ordination of the services to ensure optimal logistics at the test facility, including decisions related to the practical installation of clients and their technology and timing of tests
- Maintenance of the test facility including routine technical maintenance and dialogue with the head of department in relation to investments and maintenance expenses
- Instruction of staff with responsibility for specific tasks such as, e.g., test facility technical operations and production of test water
- Principal scientific expert with responsibility for the overall scientific quality of the services including compliance with official guidelines and protocols and requirements from classification societies; this implies input to the QAPP, revisions and implementation of SOPs, and contributions to data interpretation and reporting in collaboration with the project manager
- Participation in discussions with the classification society on important matters, particularly draft and final reports, together with the project manager

4.4 Staffing, planning and project execution

Head of projects Jens Tørsløv (Ph.D.) has the overall responsibility for allocation of staff, planning and project execution in coordination with the business area manager or the project manager as appropriate.

Laboratory manager Anja Kamper (M.Sc.) allocates laboratory technicians for a specific project as part of the laboratory capacity planning by allocation of responsibility from the head of projects. Furthermore, the laboratory manager appoints one or more test co-ordinators among the laboratory technicians or the academic staff for on-site coordination of land-based test cycles.

4.5 Project management

The **project manager** is responsible for the management and efficient performance of the project in accordance with the contract between the client and DHI, the QMP and the QAPP.

The project manager's tasks include:

- Organisation and management of the project

- Meetings and other communication with the client to ensure that all necessary information is available in due time
- Preparation of the draft and final QAPP with detailed description of the project, including time schedule of activities and deliverables; the QAPP shall be made available to all staff participating in the project
- Facilitation of the process for comments and responses to the draft QAPP in dialogue with the client and the classification society
- Preparation of amendments and deviations to the QAPP
- Communication of the project time schedule to the classification society to enable external audit
- Participation in discussions with the classification society on important matters, particularly draft and final reports, together with the business area manager
- Co-ordination and dialogue with the laboratory manager in relation to the practical organisation of work involving laboratory technicians; the project manager shall in due time inform the laboratory manager on the types of tests and the required capacity to enable laboratory capacity planning
- Contracts with subcontractors as appropriate for meeting the project deliverables (e.g. chemical analytical laboratory)
- Approval of initiation of the test cycles and interruption of test cycles, e.g. in case of irregularity
- Preparation of reports

4.6 Academic staff, laboratory staff and secretaries

The tasks of the academic staff, the laboratory staff and the secretaries include:

- Maintenance of materials and equipment
- Test facility technical operations
- Test co-ordinator function, i.e. co-ordination and keeping timely records of the activities at the test facility during land-based tests
- Production of test water and monitoring of test water quality
- Sampling at the test facility
- Analysis and data processing, including data-level QC
- Contributions to test reports
- Archiving of documents and raw data
- Contributions to QAPPs and SOPs

5 PERFORMANCE OF PROJECT

5.1 Contract

A contract between the client and DHI is negotiated and signed according to the DHI manual for project management.

5.2 Quality Assurance Project Plan

The QAPP corresponds to the quality assurance plan in the DHI Business Management System and is a project specific document describing the technology to be tested, the test facility, and other conditions affecting the actual design and implementation of the study. The QAPP is required for performance evaluation of BWMS in land-based or shipboard tests conducted according to international guidelines, but a QAPP may be established for any study where a formal study protocol is needed.

The QAPP is

- Prepared by the project manager
- Signed by the project manager and the quality supervisor (head of department)
- Forwarded to the classification society for review and comments
- Forwarded to the client for review, acceptance and signature.

The QAPP typically includes the following titles:

1. Project description and treatment performance objectives
2. Project organisation and personnel responsibilities
3. Description of the testing laboratory
4. Description of ballast water management system
5. Experimental design
6. Challenge conditions
7. Sampling and analysis plan
8. Data management, analyses and reporting
9. Validity criteria
10. Pass criteria
11. Quality assurance and control
12. Time schedule
13. References

Amendments and deviations to the QAPP are approved and signed by the project manager. Amendments describe planned changes whereas deviations describe unplanned changes to the QAPP.

The QAPP is subject to internal audit in accordance with the procedures for internal audit of the DHI Quality Management System.

5.3 Services

The project will be conducted as described in the QAPP and subsequent amendments and deviations or, alternatively, as described in the contract between the client and DHI for projects for which no QAPP is prepared.

5.3.1 Pilot tests

Pilot tests can be initiated when the technology (or BWMS) is ready for testing and DHI's deliverables are defined. With the purpose to identify problems and appropriate

adjustments of the technology, pilot tests may e.g. be conducted in the laboratory or at the test facility. Initiation of testing is decided by the project manager in agreement with the client.

5.3.2 Land-based tests

Land-based tests can be initiated when the technology, typically a fully integrated BWMS, is installed and ready for operation. Initiation of testing is decided by the project manager in agreement with the client.

The project manager decides when a test cycle in the land-based test is completed and valid, when appropriate by reference to the IMO G8 or G9 guidelines /2; 3/, US standards /4; 5/ or other standards. If required, the project manager can decide to interrupt a test cycle due to technical malfunctioning of the test facility or the technology, insufficient state of biological or physical parameters or for other reasons related to the quality of the test water.

5.3.3 Shipboard tests

Shipboard testing can be initiated when the technology, typically a fully integrated BWMS, is installed on the vessel and ready for operation. Initiation of testing is decided by the project manager in agreement with the client.

The project manager decides when a test cycle in the shipboard test is completed and valid by reference to the IMO G8 guidelines /2/ or, if appropriate, to US standards /4; 5/. If required, the project manager can decide to interrupt a test cycle due to technical malfunctioning of the technology, insufficient state of biological or physical parameters or for other reasons related to the water quality.

5.4 Reports

Reports are prepared with the details, format and language described in the contract between the client and DHI.

5.4.1 Performance evaluation of BWMS aiming at type approval

For land-based or shipboard tests of BWMS conducted as part of the type approval process (e.g. under the IMO convention or U.S. Coast Guard final rule), the report is typically structured by use of the appropriate headings in the QAPP.

The report shall include all relevant technical and analytical data and will typically contain the following items:

- Name of the client
- Executive summary
- Introduction (including a description of the test facility)
- Experimental design (including the dates for initiation and completion of tests or test cycles and procedures stated in the approved QAPP)
- Results (presented in summarizing tables and as raw data)
- Description of the BWMS (provided by the client)
- The signed QMP and QAPP with all amendments and deviations

The report shall be signed by the project manager and the head of projects.

The final report will be prepared in English and forwarded to the client.

6 QUALITY MANAGEMENT PROCESSES

6.1 Quality assurance

The services are conducted in accordance with the principles of ISO 9001 by using the DHI Business Management System and the procedures in the QMP. The DHI Business Management System is found compliant with ISO 9001 as part of the ISO 17025 accreditation of the DHI environmental laboratory.

The DHI quality manager is responsible for assigning a trained internal auditor from DHI's Quality Assurance Unit to each project in accordance with the procedures for internal audit in the DHI Business Management System (section on Quality). The internal auditor shall not be involved in solving the specific project or in any project deliverables.

The DHI Business Management System (section on Quality; Internal Audit) describes procedures for audit and evaluation and the process of periodic internal auditing of projects and activities including audit responsibilities and planning, auditor training and competences and audit reporting.

The DHI Business Management System (section on Quality; Correction and Prevention) describes procedures for corrective actions, i.e. how deviations identified during operation and auditing are corrected and how future occurrence of the same deviations is prevented (preventive actions).

6.2 Document and record control

The DHI Business Management System (section on Quality; Documents and Records) includes a procedure describing the process of drafting, revising and approving documentation.

The DHI Business Management System (section on Quality/ Laboratory Analysis/ Testing and Products with reference to SOPs 30/921 and 30/937) describes how records of the test are stored, transferred, maintained and controlled in order to ensure data integrity for a period defined in the QAPP, but not shorter than five (5) years after issue of the final report.

6.3 Subcontractor management

The DHI Business Management System (Section on Consulting / Administration / Contracting) describes how it is ensured that subcontractors follow quality requirements.

In addition, analytical laboratories providing analyses of any kind should:

- Maintain an ISO 17025 accreditation with the quality management system required herein.

- Apply accredited analytical methods when available.
- Apply other methods according to either international standard methods or in-house methods that are in all cases validated as required for accredited methods.

SOP 30/700 furthermore describes how it is ensured that purchased items such as chemicals and glassware are controlled, accepted and calibrated.

6.4 Staff competence management

The DHI Business Management System (section on Human Resources; Development) describes how it is ensured that the projects are conducted by staff with adequate competences and knowledge. This is done by maintaining a list of functions in the test process with competence requirements and responsibilities. The list is supported by reference to staff files in the DHI CV database.

6.5 Facility management

The DHI Business Management System (Laboratory Analysis and Testing with reference to SOP 30/945) describes how it is ensured that facilities and equipment are available and fit for the purposes.

6.6 Management review

The DHI Business Management System (section on Quality; Management Review) describes how the DHI management is ensuring that DHI Ballast Water Centre (Denmark) is working according to this quality manual through mechanisms such as e.g. an annual management review process.

The quality manager is responsible for maintenance and development of the quality system and for the internal auditing of all aspects of the system – with daily reference to the Director, Group R&D and Quality Management. The DHI Business Management System contains rules for reviews of the quality system.

6.7 Complaint management

The DHI Business Management System (section on Customer Satisfaction) describes how complaints are recorded, resolved and reported. If not resolved, complaints are handled according to the contract between the client and DHI.

7 REFERENCES

/1/ IMO. International Convention for the Control and Management of Ships' Ballast Water and Sediments. London. International Maritime Organization, 2004.

/2/ MEPC. Guidelines for Approval of Ballast Water Management Systems (G8). Resolution MEPC.174(58). Adopted 10th October 2008.

/3/ MEPC. Procedure for Approval of Ballast Water Management Systems that Make Use of Active Substances (G9). Resolution MEPC.126(53) Adopted 22nd July 2005.

/4/ U.S. Coast Guard. Standards for Living Organisms in Ships' Ballast Water Discharged in U.S. Waters. Federal Register, Vol. 77, No. 57, March 23, 2012.

/5/ U.S. Environmental Protection Agency, Environmental Technology Verification Program. Generic Protocol for the Verification of Ballast Water Treatment Technology. EPA/600/R-10/146, September 2010.

APPENDIX A

BMWS testing-specific Standard Operating Procedures (SOPs)

SUBJECT/SUBSUBJECT	SOP NO.
ANALYTICAL METHOD ZOOPLANKTON ANALYSIS (≥50 µm)	30/1700:05
ANALYTICAL METHOD MICROSCOPIC ENUMERATION AND IDENTIFICATION OF MICROORGANISMS (LUGOL AND CMFDA/FDA)	30/1701:03
ANALYTICAL METHOD DETERMINING PRIMARY PRODUCTION OF MICROALGAE	30/1702:04
ANALYTICAL METHOD DETERMINING DIVERSITY OF MICROALGAE COMMUNITIES BY HPLC ANALYSIS OF PIGMENTS	30/1703:03
ANALYTICAL METHOD DETERMINATION OF VIABLE ALGAE BY MPN	30/1704:03
MICROBIOLOGICAL TESTS DETERMINATION OF TOTAL NUMBER OF BACTERIA BY EPIFLUORESCENCE MICROSCOPY	30/1705:03
MICROBIOLOGICAL TESTS DETERMINATION OF HETEROTROPHIC PLATE COUNT	30/1706:03
MICROBIOLOGICAL TESTS DETERMINATION OF *VIBRIO CHOLERAE* IN WATER	30/1707:03
MICROBIOLOGICAL TESTS DETERMINATION OF TOTAL COLIFORM, *E.COLI* AND ENTEROCOCCI Colilert*-18 AND Enterolert-E	30/1708:03
MEASUREMENT METHOD OZONE MEASUREMENT IN WATER	30/1730:02
MEASUREMENT METHOD OZONE MEASUREMENT IN AIR	30/1731:02
MEASUREMENT METHOD TRO MEASUREMENT IN WATER	30/1732:02
HARVESTING, CULTURING AND ADDITION OF ORGANISMS	30/1734:04
COLLECTION OF SEAWATER	30/1735:03
COLLECTION OF FRESH WATER	30/1736:02
CRITERIA FOR TEST WATER ADDITION OF DOC, POC, MM AND BRINE	30/1737:03
SAMPLING PREPARATION, SUBSAMPLING AND TRANSPORTATION OF SAMPLES	30/1738:03
DATABASE SAMPLES, LABELS AND DATA SHEETS	30/1750:01
OPERATION OF THE DHI MTEF	30/1762:03
CLEANING RETENTION TANKS; PIPINGS AND OTHER EQUIPMENT AT TEST SITE	30/1763:03
MEASUREMENT METHOD ON-LINE MONITORING OF PRESSURE, TEMPERATURE, FLOW RATES AND QUALITY PARAMETERS AT TEST SITE	30/1764:02
MEASUREMENT METHOD FLUORESCENCE	30/1765:02
MEASUREMENT METHOD TURBIDITY	30/1766:03
HEALTH AND SAFETY ENSURING WORKER HEALTH AND SAFETY AT TEST SITE	30/1767:02

SUBJECT/SUBSUBJECT	SOP NO.
MEASUREMENT METHOD DETERMINATION OF TSS	30/1768:02
MEASUREMENT METHOD DETERMINATION OF DOC AND POC	30/1769:03

APPENDIX B

Overview of lists

Overview of lists

The lists mentioned below are kept together with the rest of quality documentation.

Classification society

DHI holds a statement describing the Classification society that has certified the DHI Maritime Technology Evaluation Facility.

List of sub-contractors

DHI keeps a list of sub-contractors used during the test. The list contains information on name of company, address, contact person, e-mail, telephone number and deliveries.

List of project managers

DHI keeps a list of appointed project managers and their experience records. The project manager's competence is documented in an available CV.

List of staff approved for functions at the test facility

DHI keeps a list of persons working at the test facility. The list contains information on the person's activities, responsibility and documentation for training. The person's competence is documented in an available CV.

List of Standard Operating Procedures

DHI keeps a list of SOPs, including those used in relation to projects conducted at the test facility.

A P P E N D I X C

Template for amendments to QAPP

AMENDMENT

AMENDMENT NUMBER

QAPP DOCUMENT TITLE AND MONTH OF ISSUE

DATE OF AMENDMENT

DESSCRIPTION OF AMENDMENT

REASON FOR AMENDMENT

IMPACT OF AMMENDMENT

PREVENTATIVE ACTION

If relevant, action to prevent that the same cause of amendment will occur in the future.

SIGNED BY

_____

Project manager

Copy to be sent to the client, the classification society and the DHI Quality Assurance Unit.

A P P E N D I X D

Template for deviations to QAPP

DEVIATION

DEVIATION NUMBER

QAPP DOCUMENT TITLE AND MONTH OF ISSUE

DATE OF DEVIATION

DESCRIPTION OF DEVIATION

REASON FOR DEVIATION

IMPACT OF DEVIATION

PREVENTIVE ACTION

If required, actions to be taken to prevent consequences of deviation

SIGNED BY

_____

Project manager

Copy to be sent to the client, the classification society and the DHI Quality Assurance Unit.

Performance evaluation in land-based test facility

PureBallast

Alfa Laval Tumba AB

Quality assurance project plan

October 2012

This report has been prepared under the DHI Business Management System certified by DNV and specifically for ballast water management system testing certified by Lloyd's Register	
Quality Management	BWMS Testing
ISO 9001	IMO Resolution MEPC.174(58) Annex part 2
Quality Management System DS/EN ISO 9001 DNV Det Norske Veritas, Præstøe Autoriseret, Danmark A/S	Lloyd's Register

Approved by
X
Approved by

Performance evaluation in land-based test facility

PureBallast

Prepared for	Alfa Laval Tumba AB
Represented by	Per Borin

DHI land-based test facility in Hundested

Project No	11811193
Classification	Confidential

Author	Michael Andersen	Michael Andersen

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Abbreviations

Abbreviation	Description
BE	Biological efficacy
BWMS	Ballast water management system
CFU	Colony forming units
CMFDA	Chloromethylfluorescein diacetate
DNV	Det Norske Veritas
DO	Dissolved oxygen
DOC	Dissolved organic carbon
FDA	Fluorescein diacetate
IMO	International Maritime Organization
ISPS	International Safety Port System
kVA	Kilovolt-ampere
MEPC	Marine Environment Protection Committee
MM	Mineral materials
MPN	Most probable number
O&M	Operation and maintenance
POC	Particulate organic carbon
PSU	Practical salinity units
QA	Quality assurance
QAPP	Quality assurance project plan
QC	Quality control
QMP	Quality management plan
SOP	Standard operating procedure
TSS	Total suspended solids
UV-T	UV transmittance
WET	Whole effluent toxicity

1 Project description and treatment performance objectives

1.1 Background and objectives

For an application for final approval, the IMO International Convention for the Control and Management of Ships' Ballast Water and Sediments /1/ requires a performance evaluation of ballast water management systems (BWMS) according to the principles laid down in Resolution MEPC.174(58) /2/, generally referred to as IMO G8 guidelines, and, for systems that make use of active substances, also Resolution MEPC.169(57) /3/, generally referred to as IMO G9 guidelines. The purpose of the performance evaluation is to assure that BWMS approved by administrations are capable of meeting the ballast water performance standard in Regulation D-2 /1/, also known as the IMO D-2 standard, in land-based and shipboard evaluations and do not cause unacceptable harm to the vessel, crew, environment or public health. The U.S. Coast Guard Standards for Living Organisms in Ships' Ballast Water Discharged in U.S. Waters /4/ (§151.2030) establish a ballast water discharge standard similar to the IMO D-2 standard. According to the U.S. Coast Guard the test set up in land-based test cycles of BWMS must operate as described in the ETV protocol test plan requirements /5/.

In this project, a performance evaluation of the PureBallast BWMS in a land-based test facility is conducted with the aim to meet the testing requirements in Resolution MEPC.174(58) /2/ and the U.S. Coast Guard standards /4/.

Currently, DHI is not recognized as an Independent Laboratory according to the U. S. Coast Guard standards, and DHI shall not be responsible if this fact is taken into account in the evaluation by the U.S. Coast Guard.

1.2 Client and ballast water management system

The client requesting the performance evaluation is:

Alfa Laval Tumba AB
Hans Stahles Väg 7
SE-147 80 Tumba
Sweden

The client is the manufacturer of the BWMS PureBallast.

1.3 Classification society

The classification society appointed by the client for inspection and certification of the project is:

Det Norske Veritas A/S (DNV)
Mariesvej 30
NO-1363 Høvik
Norway

1.4 Testing laboratory

The project is conducted by DHI Denmark (www.dhigroup.com) as part of the services under DHI Ballast Water Centre (Denmark) with the following facilities:

Mailing address:

DHI
Agern Allé 5

DK-2970 Hørsholm
Denmark
Att. Torben Madsen

DHI Maritime Technology Evaluation Facility
Færgevejen
DK-3390 Hundested
Denmark

The testing laboratory and its facilities are described in detail in Chapter 3.

The project manager for this project is environmental engineer Michael Andersen.

2 Project organisation and personnel responsibilities

The project organisation is illustrated in Figure 2.1.

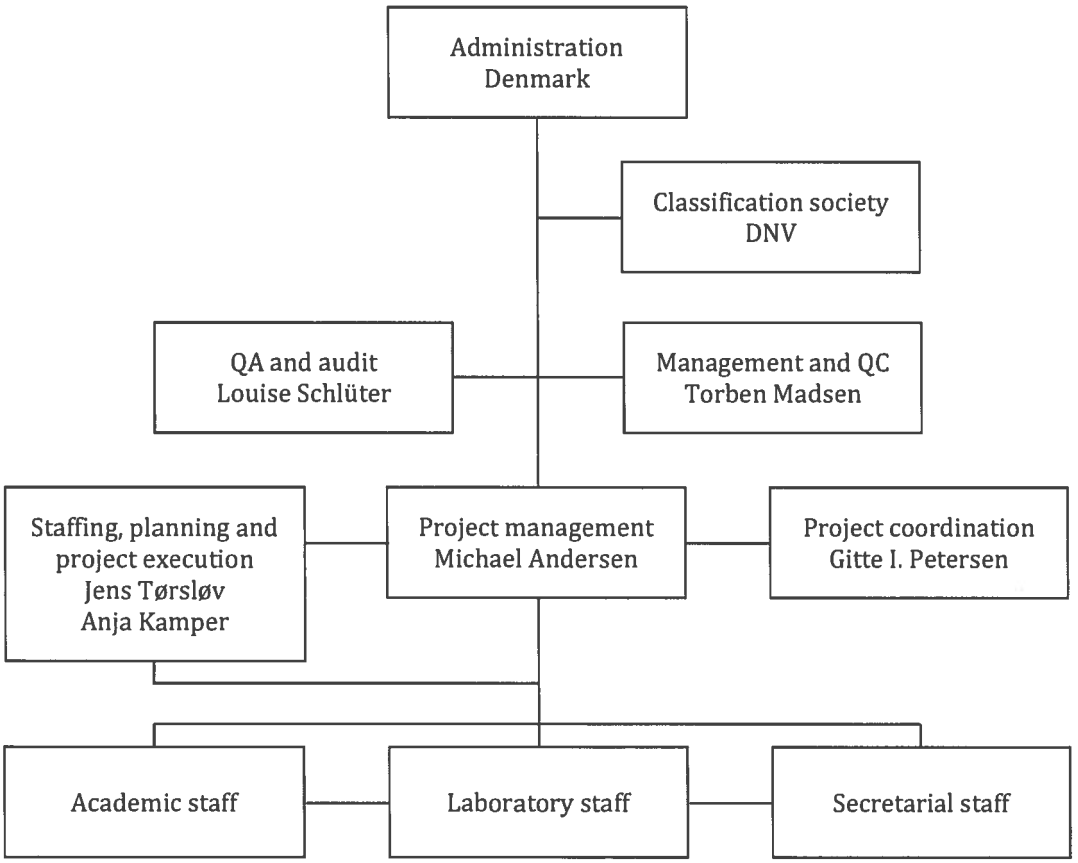

Figure 2.1 Project organisation

2.1 Quality assurance

Senior biologist Louise Schlüter (Ph.D.) is assigned by DHI's Quality Assurance (QA) Unit as internal auditor (see Chapter 11). This includes the following tasks:

- Drafting of a plan for quality assurance
- Monitoring of compliance with the quality management plan (QMP), the quality assurance project plan (QAPP) and the standard operating procedures (SOPs) by audit including the project manager and the laboratory staff

- Monitoring compliance with the appropriate guidelines by audit including the project manager
- Verification of the presence of applicable staff training records
- Drafting of audit reports and verification that audit responses are appropriate and that corrective action has been implemented effectively
- Verification that the final product complies with DHIs standards for QA (Chapter 11) and, particularly, the QMP, the QAPP and the guidelines

2.2 Management and quality control

Head of department Torben Madsen (Ph.D.) is quality supervisor for all projects and has the overall responsibility for the services under DHI Ballast Water Centre, Denmark. This includes the following tasks:

- Member of the Ballast Water Test Facility Board for DHI Ballast Water Centre
- Overall responsibility for the test facility and the DHI Environmental Laboratory including health and safety in the work place and decisions on investments and maintenance expenses
- Negotiation of contracts with clients
- Appointment of project managers and staff responsible for quality control (QC) of individual data (data-level QC) and maintenance of staff experience records (allocation of projects managers for specific projects is the responsibility of the head of projects)
- Maintenance of the QMP /6/ with updated versions as appropriate
- Maintenance of generic standards that can serve as formats for drafting the QAPP and approval of the methods applied in land-based and shipboard tests
- Quality control of the QAPP, SOPs and all project proposals, deliverables and reports
- Documentation in relation to
    - Staff training and experience
    - Facilities and their maintenance
    - Records of complaints

2.3 Project coordination

Business area manager Gitte I. Petersen (Ph.D.) is responsible for the coordination, timely execution and the overall scientific quality of the services. This includes the following tasks:

- Business development and marketing
- Co-ordination of the services to ensure optimal logistics at the test facility, including decisions related to the practical installation of clients and their technology and timing of tests
- Maintenance of the test facility including routine technical maintenance and dialogue with the head of department in relation to investments and maintenance expenses
- Instruction of staff with responsibility for specific tasks such as test facility technical operations and production of test water
- Principal scientific expert with responsibility for the overall scientific quality of the services, including compliance with official guidelines and protocols and requirements from classification societies; this implies input to the QAPP, revisions and implementation of SOPs, and contributions to data interpretation and reporting in collaboration with the project manager

- Participation in discussions with the classification society on important matters, particularly draft and final reports, together with the project manager

2.4 Staffing, planning and project execution

Head of projects Jens Tørsløv (Ph.D.) has the overall responsibility for allocation of staff, planning and project execution in coordination with the business area manager or the project manager as appropriate.

Laboratory manager Anja Kamper (M.Sc.) allocates laboratory technicians for specific projects as part of the laboratory capacity planning by allocation of responsibility from the head of projects. Furthermore, the laboratory manager appoints one or more test co-ordinators among the laboratory technicians or the academic staff for on-site co-ordination of land-based test cycles.

2.5 Project management

The project manager is responsible for the management and efficient performance of the project in accordance with the contract between the client and DHI, with the QMP and with the QAPP.

The project manager's tasks include:

- Organisation and management of the project
- Meetings and other communication with the client to ensure that all necessary information is available in due time
- Preparation of the draft and final QAPP with detailed description of the project, including time schedule of activities and deliverables; the QAPP shall be made available to all staff participating in the project
- Facilitation of the process for comments and responses to the draft QAPP in dialogue with the client and the classification society
- Preparation of potential amendments and deviations to the QAPP
- Communication of the project time schedule to the classification society to enable external audit
- Participation in discussions with the classification society on important matters, particularly draft and final reports, together with the business area manager
- Co-ordination and dialogue with the laboratory manager in relation to the practical organisation of work involving laboratory technicians; the project manager shall in due time inform the laboratory manager of the types of tests and the required capacity to enable laboratory capacity planning
- Contracts with subcontractors as appropriate for meeting the project deliverables (e.g. chemical analytical laboratory)
- Approval of initiation of the test cycles and interruption of test cycles, e.g. in case of irregularity
- Preparation of reports

2.6 Academic, laboratory and secretarial staff

The tasks of the academic, the laboratory and the secretarial staff include:

- Maintenance of materials and equipment
- Test facility technical operations
- Test co-ordinator function, i.e. co-ordination and keeping of timely records of the activities at the test facility during land-based tests
- Production of test water and monitoring of test water quality
- Sampling at the test facility
- Analysis and data processing, including data-level QC
- Contributions to test reports
- Archiving of documents and raw data
- Contributions to QAPPs and SOPs

3 Description of testing laboratory

3.1 DHI Denmark

DHI is an independent, international consulting and research organisation established in Denmark and today represented in all regions of the world with a total of more than 1,000 employees. Our objectives are to advance technological development, governance and competence in the fields of water, environment and health. DHI works with governmental agencies and authorities, contractors, consultants and numerous industries.

DHI has no involvement, intellectual or financial, in the mechanics, design or marketing of the products and technologies that are being evaluated. To ensure that DHI's tests are uncompromised by any real or perceived individual or team bias relative to test outcomes, DHI's test activities are subject to rigorous quality assurance (QA), quality control (QC) and documentation.

DHI has land-based test facilities in Denmark and Singapore. DHI's services related to performance evaluation and type approval of BWMS are organized in the DHI Ballast Water Centre between DHI Denmark and DHI Singapore, which is managed by the Ballast Water Test Facility Board. DHI established a land-based test facility in Hundested, Denmark, in June 2010.

DHI Ballast Water Centre (Denmark) holds a Certificate of Compliance issued by Lloyd's Register for the performance of land-based and shipboard testing of BWMS (Appendix A).

3.2 DHI Environmental Laboratory

DHI's Environmental Laboratory has an accreditation according to ISO 17025 /7/ and is authorized to carry out ecotoxicological studies in compliance with the OECD Principles of Good Laboratory Practice (GLP) /8/.

DHI's Environmental Laboratory and staff normally analyse all samples collected during the performance evaluation of BWMS. If required, specialized chemical analyses of, e.g., active substances or disinfection by-products, are conducted by a subcontractor identified in the section on Subcontractors.

3.3 DHI Maritime Technology Evaluation Facility

The travel time from the DHI Maritime Technology Evaluation Facility (hereafter the 'test facility') to the DHI Environmental Laboratory is approx. 50 min, which enables analysis or treatment of the samples within 6 hours.

The test facility is used to conduct biological evaluations of maritime technologies. The test facility is covered by the International Safety Port System (ISPS). Hundested Harbour is registered at IMO's website (Port facilities) under Port ID No. 266076DKHUN, Port facility 1651.

The test facility includes seven cylindrical tanks constructed in galvanized steel and coated with a non-toxic top coating:

- One open 750-m^3 source tank, Tank D in Figure 3.1. The source tank is equipped with a propeller, which creates a slow circulation in order to maintain the homogeneity of the test water. A bridge across the top of the source tank is established for monitoring the homogeneity.
- Six closed 250-m^3 retention tanks, Tanks A1, B1, C1, A2, B2 and C2 in Figure 3.1. Tanks A1 and A2 are also described as 'control tanks' and are used for untreated test water. Tanks B1, C1, B2 and C2 are retention tanks for treated test water. Each of the six retention tanks is equipped with a submersible agitator (with three-blade propeller) to create a slow circulation in order to maintain homogeneity of the test water.

The piping connecting source tank, control tanks, retention tanks, pump and BWMS is made of polyethylene. The diameters are 315 mm and 350 mm for the piping connecting the A1, B1 and C1 tanks and 400 mm and 500 mm for the piping connecting the A2, B2 and C2 tanks.

The piping system connecting the source tank and the retention tanks is equipped with sampling ports. The sampling ports are equipped with the following sample outlets:

1. Sample outlet for ≥1-m^3 samples (to be used for analysis of organisms ≥50 µm)
2. Sample outlet for ≥10-L samples (to be used for analysis of organisms ≥50 µm and organisms ≥10 to <50 µm)
3. Sample outlet for microbiology samples
4. Sample outlet for samples for analysis of dissolved organic carbon (DOC), particulate organic carbon (POC), total suspended solids (TSS) and transmittance

The test facility is equipped with sensors for automatic logging of flow, pressure, water levels, temperature, dissolved oxygen, pH, salinity and turbidity.

The test facility includes a main pump with a flow performance of 250-500 m^3/hour. By use of a harbour piping, this pump can be used to provide a continuous flow of brackish water directly from the harbour to the BWMS with a capacity of up to approx. 300 m^3/hour. Furthermore, the test facility includes electrical generator power supply up to 150 kVA.

If needed to fulfil the test water quality requirements, appropriate volumes of cultivated organisms can be added to the source tank by an auxiliary pump.

The exact configuration of the test facility piping and equipment may be subject to minor changes.

The procedures, guidelines or characteristics for analyses, operations or tests performed in the DHI Environmental Laboratory, at the test facility or on board a vessel are described in SOPs.

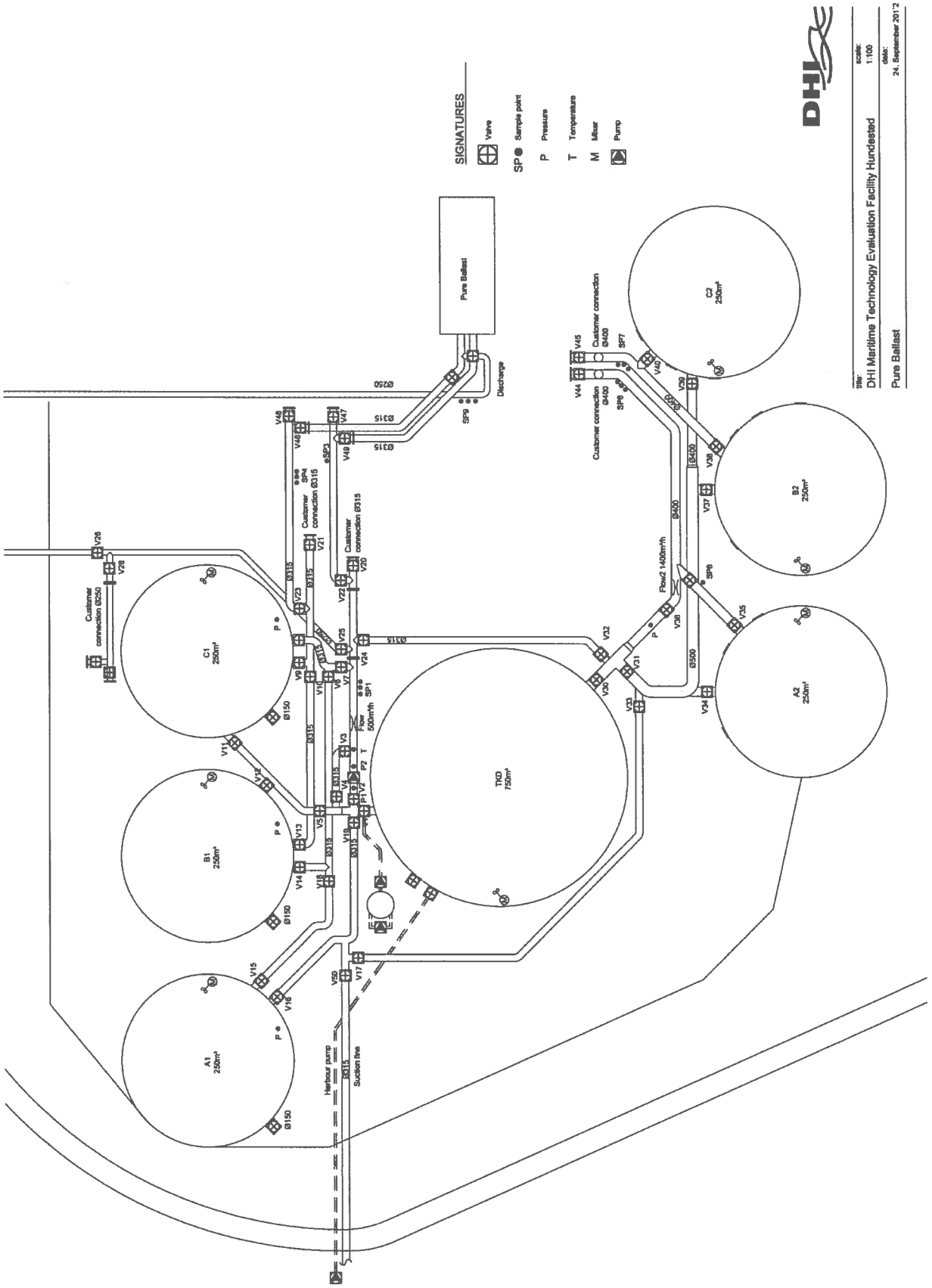

Figure 3.1 DHI Maritime Technology Evaluation Facility, Hundested, Denmark

3.4 Subcontractors

DTU Food
Zoonoselab
Mørkhøj Bygade 19, Bygning H
DK-2860 Søborg

For verification of *Vibrio cholerae* according to DHI SOP 30/1707.

4 Description of ballast water management system

4.1 Technology performance claims

Alfa Laval Tumba AB states that the PureBallast BWMS meets the following treatment and operation standards (with reference to the information required in the ETV protocol /5/, Section 3.2).

The PureBallast BWMS is designed to accomplish the ballast water discharge standard according to IMO D-2 / and U.S. Coast Guard final rule /3/, §151.2030, which should be supported by quantitative measures of biological treatment efficacy expressed as a concentration upon discharge of the specified organism size classes

The biological treatment efficacy stated above can be achieved by the following quantitative measures of operational performance

- The main principle of PureBallast treatment is filtration followed by an advanced oxidation technology (AOT).
- The AOT reactor is available in two sizes, one with a Treatment Rated Capacity (TRC) of 310 m^3/h and one with a Treatment Rated capacity (TRC) of 1030 m^3/h. To achieve a system with higher flow capacity it is possible to parallel connect several reactors.

The maritime environmental conditions where the PureBallast BWMS can be expected to achieve the biological treatment efficacy stated above

- The maritime environmental conditions as defined in resolution MEPC.174 (58) Guidelines for approval of Ballast Water Management Systems (G8) and the EPA/600/R-10/146 Generic Protocol for the verification of Ballast Water Treatment Technology (ETV).
- Chemical and biological challenge water quality criteria as defined in resolution MEPC.174 (58) Guidelines for approval of Ballast Water Management Systems (G8) and the EPA/600/R-10/146 Generic Protocol for the verification of Ballast Water Treatment Technology (ETV).
- The most challenging water quality condition for UV light based systems as PureBallast BWMS is the treated waters UV transmittance. PureBallast BWTS is able to treat water with UV Transmittance (UVT @254 nm) down to at least 50% at TRC.
- Challenge water temperature 0-40°C

Concentration of disinfection residuals, by-products and toxicity for relevant systems

- The process in PureBallast AOT reactor operates without addition of chemicals using the synergistic effects of in situ produced free radicals and UV-photons to inactivate microorganisms. The action of reactive free radicals is of temporal nature, i.e. these species are so short-lived (micro-millisecond time-scale) that they are not observable outside the AOT-treatment unit. The actual UV radiation affects only the surfaces that are directly illuminated, i.e. inside the AOT unit. The only environmental concern of the PureBallast treatment system might be attributed to the reaction products. Chemical analysis of water treated by

PureBallast BWMS has shown that it is not possibly to detect any production of residual oxidants (TRO) or change in pH in the water.

Required operational and maintenance conditions (operator time, power requirements, chemical consumption requirements, reliability, etc.)

- The maximum power requirement is 0.1 kW per treated cubic meter of water.
- Estimated operation time UV lamps 3000h
- The process in PureBallast AOT reactor operates without addition of chemicals.
- To ensure full performance in PureBallast, a cleaning cycle is to be performed within 30 hours after operation. The purpose is to keep the quartz sleeves covering the UV lamps free from scaling, which otherwise would decreases the efficiency of the AOT.

4.2 Technology and process description

The technology and process description including the appropriate sections of the format for the Technical Data Package described in Section 3.10 of the ETV protocol /5/, with safety and environmental hazards and precautions, and photographs or drawings is enclosed in Appendix B.

4.3 Physical and electrical interfaces between the BWMS and the test facility

The PureBallast BWMS pipe line 201 *ballast water inlet/outlet* will be connected to the test facility valves V49 for inlet water and V46 for treated water to retention tanks B1 and C1 (see Figure 3.1). For de-ballast operations water from retention tank B1 or C1 will be pumped to the PureBallast BWMS through V49 and a separate piping section will be established for discharge of water to the harbour. Furthermore, a BWMS-specific pipe section will be established for backwashing from the BWMS filtration technology. Potable water will be connected to the PureBallast BWMS pipe line 201 *cooling water – reactor*.

The electrical power supply to the PureBallast BWMS will be delivered by the test facility generator. A cable from an onsite switchboard is connected to a socket in the PureBallast BWMS. Pneumatic air is supplied to the PureBallast BWMS from an external compressor.

5 Experimental design

5.1 Installation and operation of the BWMS

The BWMS shall be ready to enter the performance evaluation. Prior to the start of the performance evaluation of the BWMS, it is the responsibility of the client to have completed all requirements for initiation of testing set forth by the classification society appointed by the client.

The client is expected to deliver the BWMS to the test facility in due time before the initiation of the performance evaluation (see Chapter 12). The BWMS shall be delivered in a container, which can protect the equipment, and installed in accordance with the directions of DHI.

The BWMS will be operated by DHI staff during all the test cycles by use of the O&M manual provided by the client as part of the Technical Data Package referred to in Section 4.2. The BWMS is assumed to reach a stable operating state and maintain this after no more than three start-up cycles with reference to Section 5.4.3 of the ETV protocol /5/.

To enable the independent technical operations by DHI, the client shall deliver appropriate training materials and/or practical training session(s) prior to the first test cycle.

5.2 Water types applied in the land-based test

The present land-based test with the PureBallast BWMS will be conducted with the following water types:

Brackish water (salinity 10-20 PSU)
Marine water (salinity >32-36 PSU)

The land-based test will include two (2) sets of biological efficacy (BE) test cycles, each consisting of five (5) replicate BE test cycles with a duration of at least five (5) days. Each set of BE test cycles will be conducted with test water representing one salinity range.

5.3 Biological efficacy verification testing

5.3.1 BWMS treatment process

The BE test cycles will be conducted by use of the source tank (Tank D), control tank (Tank A1) and one retention tank per test cycle (Tank B1 or C1) (Figure 3.1).

The following steps will be involved in the treatment of the test water in the BWMS (for definition and characterisation of test water, see Section 6.1):

1. A fraction of the test water (minimum 200 m^3 and maximum 250 m^3) contained in the source tank will be transferred to the BWMS by pumping and treated here, after which it will be transferred to one of the retention tanks (treated water).

2. Another fraction of the same test water (minimum 200 m^3 and maximum 250 m^3) will be pumped directly into the control tank without passing the BWMS (control water). The control water serves as a control of BWMS performance.

3. Piping system and sample ports will be cleaned (DHI SOP 30/1763).

For each BE test cycle, a minimum operational period of one (1) hour is required although this may be extended if flow rates are lower than 200 m^3 per hour (as described in Section 5.4.5 in the ETV protocol /5/). The PureBallast BWMS will be tested at a flow rate of 315 m^3 per hour (nominal flow rate of 300 m^3 per hour plus 5%) and, therefore, it is not possible to comply with the minimum operational period of one hour. Operation and maintenance testing will be conducted to test the operational aspects of the BWMS as described in Section 5.4.

During ballasting, the flow, pressure, temperature, dissolved oxygen, pH, salinity, turbidity and water levels in the tanks will be recorded automatically (DHI SOP 30/1764).

Samples will be collected before and after first treatment by use of the relevant sample ports. Sampling will be initiated when the flow rate has reached steady-state conditions, i.e. up to 5 minutes from start of operation (DHI SOP 30/1738; DHI SOP 30/1762). Samples will be labelled according to procedures described in DHI SOP 30/1750.

5.3.2 Storage of treated and untreated test water

Following the treatment of the test water in the BWMS, the treated water will be stored in the retention tank for at least five days ± 4 hours. The same storage time will be applied for the control water.

5.3.3 Second treatment and discharge of test water

1. Treated water contained in the retention tank will be pumped through the BWMS for second treatment, after which it is discharged into the harbour (treated discharge water)

2. Control water contained in the control tank will be discharged into the harbour (control discharge water)

3. The retention tanks, piping system and sample ports will be cleaned (DHI SOP 30/1763)

During de-ballasting, the flow, pressure, water temperature, dissolved oxygen, pH, salinity, turbidity and water levels in the tanks will be recorded automatically (DHI SOP 30/1764).

Samples of the treated discharge water will be collected by use of the sampling ports on the BWMS discharge line whereas samples of the control discharge water will be collected by use of sampling ports on the test facility discharge line. Isokinetic sampling methodology with fixed sample volumes will be applied according to principles described in MEPC.173(58) (G2) /9/.

5.4 Operation and maintenance testing

The operation and maintenance (O&M) testing of the BWMS shall distribute testing of a minimum treated volume of 10,000 m^3 amongst the BE test cycles. The minimum total volume for the O&M test cycles will be achieved by conducting five O&M test cycles, each with a minimum treated volume of 2,000 m^3.

For each O&M test cycle, a minimum operational period of one (1) hour is required although this may be extended if flow rates are lower than 200 m^3 per hour (as described in Section 5.4.5 of the ETV protocol /5/).

6 Challenge conditions

6.1 Source water and test water

6.1.1 Source water applied in the land-based test

Source water means the body of water, from which water is drawn for the land-based test. The IMO G8 guidelines /2/ and the ETV protocol /5/ describe three distinct water types that may be applied in the land-based test:

Fresh water (salinity <1 PSU)
Brackish water (salinity 10-20 PSU)
Marine water (salinity >32-36 PSU)

When fresh water is used, the source water will be collected in the Arresø Canal according to DHI SOP 30/1736 on collection of fresh water. Organism densities in the collected fresh water often exceed the minimum criteria for live organisms in test water with an order of magnitude allowing for dilution of the natural fresh water with potable water.

When brackish water is used, the source water will be collected immediately south of the pier adjacent to the test facility according to DHI SOP 30/1735; under normal conditions, the natural salinity of the source water will be 15-20 PSU.

When marine water is used, the source water will be collected immediately south of the pier adjacent to the test facility according to DHI SOP 30/1735, and brine will be added to achieve the required salinity.

6.1.2 Test water – water quality characteristics

Test water (equivalent to the term challenge water /4; 5/) means the inlet water as contained in the source tank just prior to treatment. In land-based tests, source water may be adjusted to achieve the required challenge conditions.

The natural concentrations of dissolved organic carbon (DOC), particulate organic carbon (POC) and total suspended solids (TSS) in the source water are analysed, after which the test water will be prepared to meet the water quality parameters in Table 6.1.

Table 6.1 Minimum water quality characteristics in compliance with the IMO G8 guidelines /2/ and the ETV protocol /5/

Parameter	Source water		
	Fresh (<1 PSU)	Brackish (10-20 PSU)	Marine (>32-36 PSU)
Dissolved organic carbon (DOC)	≥ 6 mg/L	≥ 6 mg/L	≥ 6 mg/L
Particulate organic carbon (POC)	>5 mg/L	≥ 5 mg/L	≥ 4 mg/L
Total suspended solid (TSS) Mineral materials (MM) ≥ 20 mg/L	>50 mg/L	≥ 50 mg/L	≥ 24 mg/L

If necessary to obtain the stated water quality parameters, the concentrations of DOC, POC and mineral materials (MM) will be increased by additions of lignin sulphonate (DOC), starch (POC) and kaolin clay (MM) as described in DHI SOP 30/1737.

6.1.3 Test water – biological organism conditions

The natural densities of live organisms in the source water are analysed with reference to size classes, after which the test water will be prepared to meet the biological parameters in Table 6.2.

Table 6.2 Minimum criteria for densities of live organisms in the test water according to the IMO G8 guidelines /2/ and the ETV protocol /5/

Organism size class	Total concentration	Diversity
≥50 µm	10^5 organisms/m³	5 species across 3 phyla
≥10 µm and <50 µm	10^3 organisms/mL	5 species across 3 phyla
<10 µm	10^4/mL as culturable aerobic heterotrophic bacteria	Not applicable

If necessary in order to obtain the stated minimum criteria, the densities of live organisms will be increased by addition of harvested indigenous organisms and/or cultured species as described in DHI SOP 30/1734. Addition of harvested and/or cultured species will be recorded in the data logging. Heterotrophic bacteria are typically present in the test water in densities exceeding the minimum criteria described in Table 6.2.

The minimum densities of live organisms in the control discharge water are presented in Table 6.3.

Table 6.3 Criteria for densities of live organisms in the control discharge water according to the IMO G8 guidelines /2/ and the ETV protocol /5/

Organism size class	Total concentration
≥ 50 µm	100 organisms/m³
≥10 µm and < 50 µm	100 organisms/mL
<10 µm	5×10^2/mL as culturable aerobic heterotrophic bacteria

7 Sampling and analysis plan

7.1 Sample overview in BE verification testing

Table 7.1 Overview of sampling and purpose of samples

Parameter	Inlet water to BWMS and control tank	Treated water (1st treatment)	Treated discharge water (2nd treatment)	Control discharge water	Sample collection
Ballasting operations					
Volume	×	×	×	×	Continuous
Pressure	×	×	×	×	Continuous
Flow	×	×	×	×	Continuous
Other parameters*	×	×	×	×	Continuous
Water quality conditions					
Temperature, salinity, turbidity, pH, DO**	×	×	×	×	Continuous
TSS, DOC***, POC*** and UV-T****	×	×	×	×	Discrete grab (3 replicates; start, middle, end)
Concentrations of live organisms					
Viable organisms ≥50 µm/m³	×*****	×	×	×	Discrete (3 replicates; time integrated)
Viable organisms ≥10 and <50 µm/mL	×	×	×	×	Discrete (3 replicates; each representing approx. a third of the operation period)
Viable organisms <10 µm/mL (heterotrophic aerobic bacteria, *E. coli*, enterococci and *Vibrio cholerae*)	×	×	×	×	Discrete grab (3 replicates; start, middle, end)
Whole Effluent Toxicity (WET)	-	-	×******	×*****	Discrete (time integrated)

* Operational parameters to ensure that the systems have been operated correctly and in accordance with the Operation and Maintenance manual
** Dissolved oxygen
*** Measured in inlet and discharge samples
**** UV-transmittance at 254 nm, 1 cm, measured in inlet samples
***** Collected as discrete grab samples (3 replicates; start, middle, end)
****** Only in BE test cycles to be decided later

Triplicate flow-integrated samples will be collected. The samples will be stored in thermo boxes with cooler bricks in the dark from the time of collection until handling of the samples at the DHI Environmental Laboratory.

7.2 Inlet water and treated water after first treatment

Table 7.2 Sampling and analysis of inlet water to BWMS and control tank

Parameter	DHI SOP	Laboratory
Organisms ≥50 µm	30/1700	DHI
Organisms ≥10 µm and <50 µm		
Microscopy	30/1701	DHI
Primary production (algae)	30/1702	DHI
Re-growth assay (algae)	30/1704	DHI
Organisms <10 µm		
Heterotrophic aerobic bacteria	30/1705	DHI
E. coli and enterococci	30/1708	DHI
Physical/chemical		
Temperature, pH, O_2, salinity and turbidity	30/1764	DHI
TSS, DOC and POC	30/1768 + 30/1769	DHI
UV-transmittance at 254 nm, 1 cm	30/1770	DHI

Table 7.3 Sampling and analysis of treated water after 1st treatment

Parameter	DHI SOP	Laboratory
Organisms ≥50 µm	30/1700	DHI
Organisms ≥10 µm and <50 µm		
Primary production (algae)	30/1702	DHI
Organisms <10 µm		
Heterotrophic aerobic bacteria	30/1705	DHI
Physical/chemical		
TSS	30/1768 + 30/1769	DHI
Temperature, pH, O_2, salinity and turbidity	30/1764	DHI

7.3 Treated discharge water and control discharge water

Table 7.4 Sampling and analysis of treated discharge water after 2nd treatment

Parameter	DHI SOP	Laboratory
Organisms ≥50 µm	30/1700	DHI
Organisms ≥10 µm and <50 µm		
Microscopy	30/1701	DHI
Primary production (algae)	30/1702	DHI
Re-growth assay (algae)	30/1704	DHI
Organisms <10 µm		
Vibrio cholerae	30/1707	DHI
E. coli and enterococci	30/1708	DHI
Physical/chemical		
Temperature, pH, O_2, salinity and turbidity	30/1764	DHI
TSS, DOC and POC	30/1768 + 30/1769	DHI
Whole Effluent Toxicity (WET)*	30/326 + 30/305 + 30/391	DHI

* Only in BE test cycles to be decided later, chronic WET tests with algae, crustacean and fish

Table 7.5 Sampling and analysis of control discharge water

Parameter	DHI SOP	Laboratory
Organisms ≥50 µm	30/1700	DHI
Organisms ≥10 µm and <50 µm		
Microscopy	30/1701	DHI
Primary production (algae)	30/1702	DHI
Re-growth assay (algae)	30/1704	DHI
Organisms <10 µm		
Heterotrophic aerobic bacteria	30/1705	DHI
Vibrio cholerae	30/1707	DHI
E. coli and enterococci	30/1708	DHI
Physical/chemical		
Temperature, pH, O_2, salinity and turbidity	30/1764	DHI
TSS, DOC and POC	30/1768 + 30/1769	DHI
Whole Effluent Toxicity (WET)*	30/326 + 30/305 + 30/391	DHI

* Only in BE test cycles to be decided later, chronic WET tests with algae, crustacean and fish

8 Data management, analyses and reporting

8.1 Data management

During the land-based test, logging of data related to

- Personnel working at the test facility
- Operational procedures and monitoring
- Sampling and analysis

is performed in accordance with the data-logging procedures described in the respective DHI SOPs. A complete overview of the DHI SOPs used for BWMS performance evaluation is presented in Appendix C.

An Access-based database and the procedures described in DHI SOP 30/1750 are used for storage of data generated from the BE test cycles and for marking completed QC of individual data. This data-level QC is made with reference to data quality indicators described in the DHI SOPs.

All generated data and all other records and information relevant to the quality and integrity of the performance evaluation, including a copy of the database file(s) and original raw data, will be retained in the archives of DHI for a period of five years after issue of the final report.

8.2 Analyses

8.2.1 Organism size class ≥50 µm

Compliance with the pass criterion in Chapter 10 will be verified by use of the direct count of organisms ≥50 µm in minimum dimension.

The concentrations of live organisms ≥50 µm in minimum dimension will be determined by use of a stereo microscope and a counting chamber according to DHI SOP 30/1700. Viable organisms will be enumerated by use of standard movement and response stimuli technique. The viable organisms will be characterized according to major taxonomic groups.

8.2.2 Organism size class ≥10 µm and <50 µm

Compliance with the pass criterion in Chapter 10 will be verified by use of the total of viable organisms determined by measuring algal re-growth using a most probable number (MPN) assay and enumeration of viable moving organisms ≥10 and <50 µm in minimum dimension that are not encompassed by the algal re-growth assay (FDA/CMFDA labelled organisms without chlorophyll).

To support the determination of concentrations of organisms in the ≥10 µm and <50 µm size class, the following analytical methods will be applied.

The concentrations of organisms and the presence of taxonomic groups in the inlet water will be determined by inverted microscopy. Inverted microscopy will also be used to determine the taxonomic groups of algae that are able to grow under the conditions applied in the algae re-growth assay. The specific methodologies applied are described in DHI SOPs 30/1701 and 30/1704.

Determining viable organisms in the ≥10 µm and <50 µm size class will be performed by vital staining with fluorescein diacetate (FDA) and chloromethylfluorescein diacetate (CMFDA) solution. FDA and CMFDA will be added to a subsample and after incubation, the subsample will be examined by use of a microscope under epifluorescence. Organisms labelled by either FDA or CMFDA will be considered viable as described in DHI SOP 30/1701. Only FDA/CMFDA labelled moving organisms will be included in the verification of compliance with the pass criteria.

Determining viable algae will be performed by measuring re-growth by use of a most probable number (MPN) assay. For the re-growth assay, a dilution series will be prepared by adding aliquots of subsample to test tubes with liquid medium. The test tubes will be incubated for 14 days at ambient temperature. The concentrations of viable algae in the inlet water, control discharge water and treated discharge water will be determined by measuring of the fluorescence in the test tubes before and after incubation according to DHI SOP 30/1704.

The algal primary production will be determined by measuring the ^{14}C fixed by photosynthesis. For each field replicate, $NaH^{14}CO_3$ (2 µCi) will be added to two subsamples. These subsamples will be incubated for approx. 75 min under light from a light panel at ambient temperature. After incubation, the samples will be filtered onto Whatman GF/D filters. The filters will be transferred to glass vials, after which acid will be added directly to the filters. The ^{14}C activity remaining in the algae on the filters after acidification will be quantified by liquid scintillation counting according to DHI SOP 30/1702.

The re-growth assay with support from the measurements of primary production is considered to provide the most reliable results to be used for a performance evaluation of a BWMS applying UV treatment as these methods are directly linked to algal growth and, thus, indicative of the ability of the organisms to establish and reproduce in the environment. Neither the algal re-growth assay nor the algal primary production analyses are limited to the ≥10 µm and <50 µm size class. These analyses include planktonic algae without reference to size.

8.2.3 Organism size class <10 µm

The concentrations of heterotrophic aerobic bacteria will be determined according to DHI SOP 30/1706 (ISO 6222). *E. coli* and enterococci will be analysed according to DHI SOP 30/1708. *Vibrio cholerae* will be analysed according to the method described in DHI SOP 30/1707.

8.2.4 Physical/chemical analyses

The measurements conducted at the test facility according to DHI SOPs 30/1764 and 30/1766 will include:

- pH
- Temperature
- Salinity
- Turbidity

- Dissolved oxygen
- Ballast system pressure
- Ballast system flow rates
- Water volume in retention tanks

The analyses conducted at the DHI Environmental Laboratory will include the following measurements:

- TSS
- POC
- DOC
- UV-transmittance at 254 nm, 1 cm

8.3 Amendments, deviations and reports

Amendments are planned changes to the QAPP. Deviations are unplanned changes. Amendments and deviations will be signed by the project manager and documented in the file and the final report.

The following reports will be prepared:

- Draft final report compiling all relevant data from the test cycles, data interpretation and conclusion
- Final report

9 Validity criteria

According to the IMO G8 guidelines, Annex, Part 2, Section 2.3.36 and ETV protocol, Section 5.4.7 /2/, /5/, a valid BE test cycle implies that:

1. Operational parameters that demonstrate that the requisite volumes are transferred and sampled and vendor-specified flows, pressures or other validation criteria are maintained
2. Water quality challenge conditions for uptake and discharge waters including toxicity sampling (if relevant) are met. Minimum water quality conditions are provided in Table 6.1.
3. Biological challenge conditions for ambient organism concentration and diversity are met. Minimum densities of live organisms are provided in Tables 6.2 and 6.3.

10 Pass criteria

A valid BE test cycle is regarded successful if it meets the performance standard for treated ballast water at discharge (IMO Regulation D-2 /1/ and United States Coast Guard /4/ (§151.2030)):

1. The average density of organisms larger than or equal to 50 µm in minimum diameter in the replicate samples shall be less than 10 viable organisms per m3 at discharge
2. The average density of organisms smaller than 50 µm and larger than or equal to 10 µm in minimum diameter in the replicate samples shall be less than 10 viable organisms per mL at discharge, based on the combined results from the MPN analysis, viability counts and levels of primary production

3. The average density of *Vibrio cholerae* (serotypes O1 and O139) shall be less than 1 colony forming unit (CFU) per 100 mL at discharge

4. The average density of *E. coli* in the replicate samples shall be less than 250 CFU per 100 mL at discharge

5. The average density of intestinal enterococci in the replicate samples shall be less than 100 CFU per 100 mL at discharge

11 Quality assurance and control

11.1 Quality assurance

The project is conducted in accordance with the principles of ISO 9001 by using the DHI Business Management System and the procedures in the QMP /6/.

The DHI quality manager is responsible for assigning a trained **internal auditor from DHI's Quality Assurance Unit** to each project in accordance with the procedures for internal audit in the DHI Business Management System (section on Quality). The internal auditor shall not be involved in solving the specific project or in any project deliverables.

The DHI Business Management System (section on Quality; Internal Audit) describes procedures for audit and evaluation and the process of periodic internal auditing of projects and activities including audit responsibilities and planning, auditor training and competences and audit reporting.

The DHI Business Management System (section on Quality; Correction and Prevention) describes procedures for corrective actions, i.e. how deviations identified during operation and auditing are corrected and how future occurrence of the same deviations is prevented (preventive actions).

11.2 Quality control

Quality control of individual data, or data-level QC, of BWMS operational conditions, sampling and analyses is conducted with reference to data quality indicators in the DHI SOPs by staff appointed for this task (see Section 2.2). Records of completed data-level QC are stored in an Access-based database (DHI SOP 30/1750), and a copy of the relevant database file(s) will be retained in the DHI archives for a period of five years after issue of the final report.

Quality control of the QAPP, DHI SOPs and all project proposals, deliverables and reports is conducted by management (see Section 2.2).

12 Time schedule

The testing is expected to be initiated on 4th October 2012. The biological efficacy testing will be performed with one test every week or two tests every second week throughout the autumn 2012 (to the extent possible).

The classification society will be regularly updated by client and/or testing laboratory as the testing progresses.

DHI decides the applied test water salinities and the timing of the test cycles within the access period.

Dependent on weather conditions and the possibilities of preparing the right test water quality, the land-based test cycles will be conducted as outlined above.

Ballasting is performed on Thursdays from approx. 08:00 am and the de-ballasting is performed on the following Tuesday from approx. 08:00 am, if at all practicable.

A draft final report will be prepared within ten (10) weeks after successful completion of the planned test cycles.

A final report will be issued three weeks after the client's approval of the draft final report.

13 References

/1/ IMO. International Convention for the Control and Management of Ships' Ballast Water and Sediments. London. International Maritime Organization, 2004.

/2/ MEPC. Guidelines for Approval of Ballast Water Management Systems (G8). Resolution MEPC.174(58). Adopted 10th October 2008.

/3/ MEPC. Procedure for Approval of Ballast Water Management Systems that Make Use of Active Substances (G9). Resolution MEPC.169(57) Adopted 4th April 2008.

/4/ U.S. Coast Guard. Standards for Living Organisms in Ships' Ballast Water Discharged in U.S. Waters. Federal Register, Vol. 77, No. 57, March 23, 2012.

/5/ U.S. Environmental Protection Agency, Environmental Technology Verification Program. Generic Protocol for the Verification of Ballast Water Treatment Technology. EPA/600/R-10/146, September 2010.

/6/ Quality management plan. Performance Evaluation of Ballast Water Management Systems. DHI Denmark. Version 3.1. May 2012.

/7/ EN ISO/IEC 17025. General requirements for the competence of testing and calibration laboratories /ISO/IEC 17025, 2005.

/8/ OECD Principles of Good Laboratory Practice (as revised in 1997). Organisation for Economic Co-operation and Development (OECD), Paris. ENV/MC/CHEM (98)17.

/9/ Resolution MEPC.173(58). Adopted on 10 October 2008. Guidelines for approval of ballast water sampling (G2).

Approval of quality assurance project plan

DHI Ballast Water Centre, Denmark

Project management Date: 03-10-2012

Michael Andersen

Quality control Date: 03-10-2012

Torben Madsen

This QAPP is accepted and my signature authorizes the study to proceed as described in this document.

Client Date: 4/10-12

Per Borin
Alfa Laval Tumba AB

APPENDIX A

Certificate of compliance, ISO 9001 certificate, accreditation and GLP authorisation

COPY

Certificate no: **DS/I093222-A**
Page 1 of 1

Certificate of Compliance

Office: **Lloyd's Register EMEA**
Copenhagen Design Support Centre, Statutory Section
Strandvejen 104A, 2nd floor
DK-2900 Hellerup
Denmark

Date: **09 May 2012**

This certificate is issued to **DHI Ballast Water Centre, Denmark**

DHI Ballast Water Centre, Denmark

The Document(s) listed in paragraph 1 of the appendix have been examined for compliance with:

- Resolution MEPC.174(58), Annex part 2

and are found to comply from quality assurance and quality control aspects subject to the following:

1.1. It is required to maintain full and accurate log files in order to demonstrate correct quality measures

1.2. The Quality Assurance Project Plan is a project specific document and should as such be subject to review and commenting prior to each project start-up.

1.3. This design appraisal document is to be kept together with quality management plan.

1.4. Subject certificate is valid until 15 June 2015.

1. The documents listed below have been examined

Drawing No.	Rev.	Title	Status	Date
Date: 07 Sep 2011	**2.3**	**Quality Management Plan**	**B**	**09 May 2012**

2. The documents listed below have been considered together with the submitted documents in the appraisal

Drawing No.	Rev.	Title
11810704	**02**	**Quality Assurance Project Plan**

Appraisal Status Key

B Examined and found to comply with §2.2, Part 2 of the annex of IMO Resolution MEPC 174 (58)

Martin Schabert
Statutory Department
Copenhagen Design Support Centre
Surveyor to Lloyd's Register EMEA

LLOYD'S REGISTER EMEA
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M Schabert
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DET NORSKE VERITAS

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Certificate No. 109333-2012-AQ-DEN-DANAK

This is to certify that

DHI Group

has been found to conform to the management system standard:

DS/EN ISO 9001:2008

This certificate is valid for the following product or service ranges:

Consulting, software, research & development and laboratory testing, analysis & products within the area of water, environment & health

Locations included in the certification will appear in the appendix.

Place and date:

Hellerup, 2012-01-10

DET NORSKE VERITAS,
BUSINESS ASSURANCE, DANMARK A/S

Jens Peter Høiseth
Managing Director

This certificate is valid until:

2015-01-10

The audit has been performed under the supervision of:

Jan Carsten Schmidt
Lead Auditor

DANAK
SYSTEM Reg.nr. 5001

Lack of fulfilment of conditions as set out in the Certification Agreement may render this certificate invalid.

Det Norske Veritas, Business Assurance, Danmark A/S
Tuborg Parkvej 8, 2., DK-2900 Hellerup, Denmark. Tel. +45 39 45 48 00, www.dnv.com / www.dnv.dk

DET NORSKE VERITAS

APPENDIX TO CERTIFICATE

This appendix refers to certificate no. 109333-2012-AQ-DEN-DANAK

DHI Group

Locations included in the certification are as follows:

Site Address	Scope:
Agern Allé 5 2970 Hørsholm, Denmark	Consulting, MIKE© by DHI Software Development, Sales & Support, Solutions Software Development, Research, Development & Innovation and Laboratory Analysis, Testing & Products
INCUBA Science Park, Gustav Wieds Vej 10 8000 Århus, Denmark	Consulting, Solutions Software Development and Research, Development & Innovation

This certificate is valid until:

2015-01-10

The audit has been performed under the supervision of:

Jan Carsten Schmidt
Lead Auditor

DANAK
SYSTEM Reg nr. 5001

Place and date:

Hellerup, 2012-01-10

DET NORSKE VERITAS,
BUSINESS ASSURANCE, DANMARK A/S

Jens Peter Høiseth
Managing Director

Lack of fulfilment of conditions as set out in the Certification Agreement may render this certificate invalid

Det Norske Veritas, Business Assurance, Danmark A/S
Tuborg Parkvej 8, 2., DK-2900 Hellerup, Denmark. Tel. +45 39 45 48 00, www.dnv.com / www.dnv.dk

Accreditation to testing COPY DANAK

Company:	**DHI**
	Agern Allé 5 **DK-2970 Hørsholm**
Registration number:	26
Valid:	**04-07-2011 to 31-07-2015**

Scope:

Testing

Product

- **Biological items for testing**
- **Chemicals, chemical products, cosmetics, fertilizers, paints**
- **Environmental samples: Air, water, soil, waste**
- **Construction products**

Test Type

- **Biological, biochemical testing**
- **Chemical testing, Analytical chemical testing**
- **Radiochemistry, radiation**
- **Sampling, laboratories accredited for sampling**

Testing is performed according to the current list of test methods approved by DANAK.

The company complies with the criteria in EN ISO/IEC 17025:2005 – General requirements for the competence of testing and calibration laboratories and demonstrates technical competence for the defined scope and the operation of a quality management system (refer joint ISO-ILAC-IAF Communiqué dated January 2009, www.danak.dk).

Issued July 4th 2011

Jesper Høy **Kirsten Jebjerg Andersen**

In case of any dispute, the Document in Danish language shall have priority

Den Danske Akkrediterings- og Metrologifond

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DANAK

GOOD LABORATORY PRACTICE

STATEMENT OF COMPLIANCE

Laboratory inspection and study audits for compliance with the OECD Principles for Good Laboratory Practice were carried out at

Laboratory: DHI

on

Dates: 21st and 22nd October 2011

The laboratory inspection and study audits have been carried out in accordance with the regulation settled in Order No. 906 of 14th September 2009 from the Danish Ministry of Environment. The laboratory has been monitored for GLP Compliance within the following scope:

Type of products:

- *Industrial chemicals*
- *Pesticides*
- *Biocides*

Type of tests:

- *Environmental toxicity studies on aquatic and terrestrial organisms.*
- *Studies of behaviour in water, soil and air, bioaccumulation*

The laboratory was found to be operating in compliance with the OECD Principles of Good Laboratory Practice.

Date: 08 August 2012

Jesper Høy
Managing director, DANAK

Kirsten Jebjerg Andersen
GLP inspector, DANAK

Den Danske Akkrediterings- og Metrologifond

APPENDIX B

Description of the ballast water management system as provided by the client

Generic system description
PureBallast 3.0

Book No. 9004783 02, rev. 0

EAT/11811193/Alfa Laval AB/QAPP/2012.10.04

Published By:
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EAT/11811193/Alfa Laval AB/QAPP/2012.10.04

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EAT/11811193/Alfa Laval AB/QAPP/2012.10.04

1 Introduction

This contains general information about the PureBallast system and its components.

1.1 Abbreviations

The table below is a list of abbreviations used in this manual.

Abbreviation	Explanation
AOT	Advanced oxidation technology
AOT module	Complete component handling the purification. Includes AOT reactor, valves and LDC module
AOT reactor	The reactor house with UV lamps purifying the water
Atex	EU directive "Appareils destinés à être utilisés en ATmosphères EXplosivles"
CIP	Cleaning in place
CIP module	Cleaning in place module. Performs the CIP cycle.
DIN	Deutche Institut für Normung
EX	Explosion-proof
I/O	Input/output (Describes a program or device handling data)
IACS	International Association of Classification Societies
ISCS	Integrated ship control system
IMO	International Maritime Organization
JIS	Japanese Industrial Standard
LED	Light emitting diode
LDC	Lamp drive cabinet.
LPS	Lamp power supply
MCB	Motor circuit breaker

EAT/11811193/Alfa Laval AB/QAPP/2012.10.04

Abbreviation	Explanation
PLC	Programmable logical controller (PureBallast control system)
UV	Ultra violet

1.2 System overview

The PureBallast system is an integral part of the vessel's ballast water system, on the discharge side of the vessel's ballast water pumps. It is equipped with a bypass valve that is controlled from the ISCS (integrated ship control system). PureBallast is also equipped with two sampling devices, one before treatment and one after treatment. This makes it possible to take samples of the ballast water according to IMO requirements.

The main principle of PureBallast treatment is filtration followed by an advanced oxidation technology (AOT). In the process PureBallast uses a patented AOT component: Wallenius AOT® reactor, which is the main stage of treatment during ballasting and deballasting. The AOT reactor is available in two sizes, one with a capacity of 300 m^3/h and one with a capacity of 1000 m^3/h. To achieve a system with higher flow capacity it is possible to parallel connect up to six AOT reactors of one size. It is not possible to combine the two sizes.

PureBallast can thereby handle flow capacities between 300 and 6000 (m^3/h.

1.2.1 Options and system variants

Apart from the size and number of AOTs, PureBallast can be ordered with options and variants. These are explained below:

Filter: Alternative filters, from defined suppliers can be ordered. The size of the filter depends on flow capacity for the specific installation. The filter size is chosen according to the suppliers recommendations.

Flange standard: Flange standard for the system can be either JIS or DIN. This will effect all components with flanges, such as the AOT, filter, CIP, flow meter and valves.

Piping size: The flow capacity defines dimension of valves, including the flow meter. For each flow capacity, it is possible to choose piping size from alternatives that has been evaluated to be suitable for respective flow capacity

Remote control: PureBallast is monitored and operated from a control panel. As an option, it is possible install up to four additional control panels. It is also possible to integrate PureBallast with the vessel's integrated ship control system (ISCS). For further information, see the *Control system* section.

Power management: It is also possible to integrate PureBallast with the vessel's power management system. This integration will allow automatic verification that there is enough power to run an operation. If not integrated, the operator must verify this manually.

EX proof system: PureBallast can be ordered in an EX proof version. The version use Atex certified equipment and a redundant safety control system to allow installation on board most types of vessels that carry potentially flammable or explosive substances.

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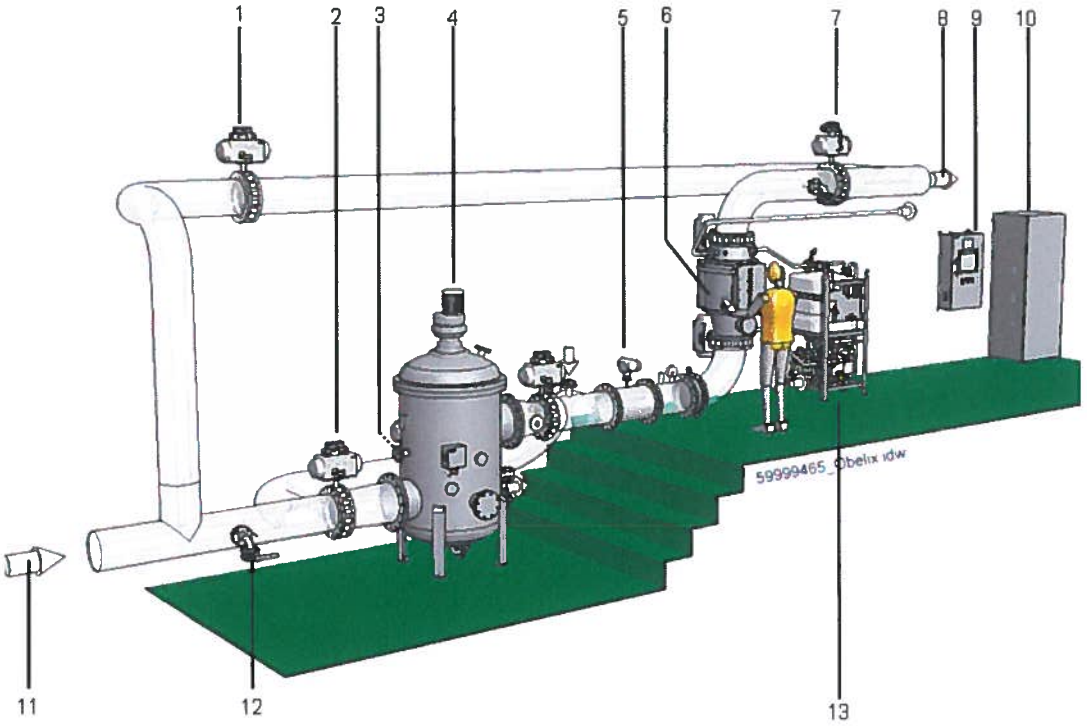
1.3 Components overview

The key components in PureBallast are shown below. Note that the filter is just an example of a filter unit; others may be chosen.



2 System overview

Example of layout with 1 AOT module (flow capacity: 1000 m³/hour).

1. *PureBallast bypass valve*
2. *Filter inlet valve*
3. *Filter bypass valve (behind filter)*
4. *Filter*
5. *Flow meter*
6. *AOT reactor*
7. *Control valve*
8. *Ballast water outlet*
9. *Control cabinet including control panel*
10. *Lamp drive cabinet (LDC)*
11. *Ballast water inlet*
12. *Sampling device (before treatment)*
13. *CIP (Cleaning in place) module*

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1.3.1 Item numbers

System components are identified by unique item numbers, for example “FIT201-1” for the flow transmitter installed before the AOT.

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2 Process overview

This section gives an overview of the main processes performed by PureBallast. In the flow chart illustrations, involved pipes are marked in bold.

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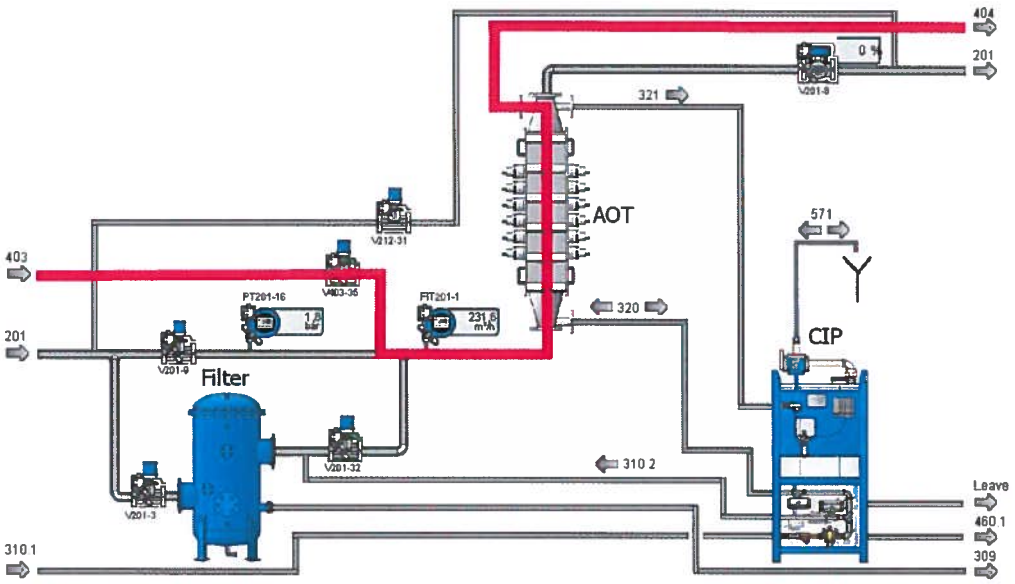
2.1 Ballast start-up

Ballasting begins with a start-up phase. The start-up can start when required power has been granted, either manually or automatically via the vessel's power management system.

During the start-up, the UV lamps are warmed up. Cooling water is pumped through the AOTs to secure that the UV lamps are not overheated. When the lamps are ready, the operator is requested to start the ballast pump.

The process flow is monitored by the flow meter to secure that there is enough flow to cool the UV lamps. If flow deviates from parameter set values, an alarm is issued and the system is shut down.



Ballast start-up

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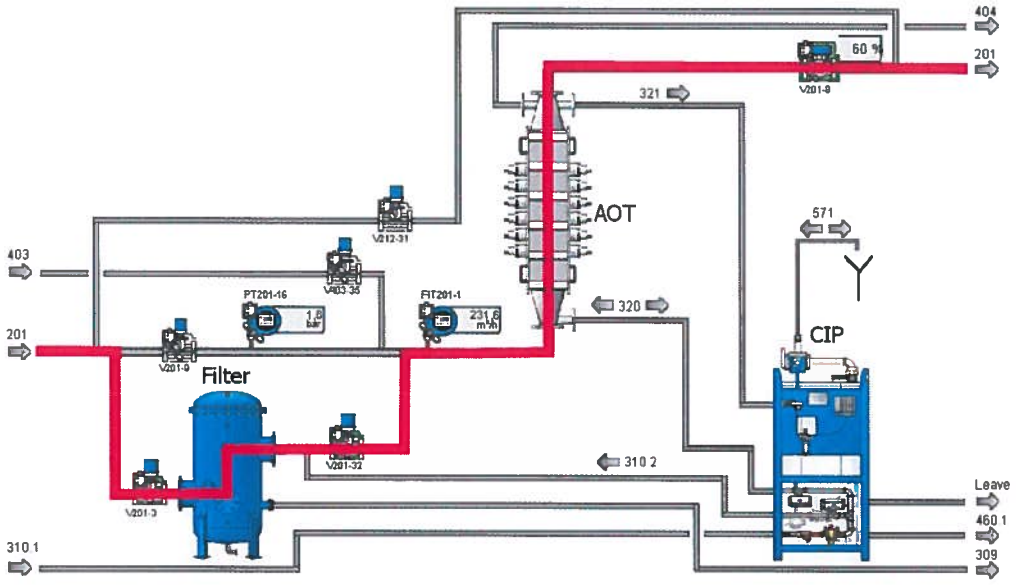
2.2 Ballasting

When the actual ballasting process starts, water is taken from the sea chest. The water passes the PureBallast filter that removes larger particles and organisms. This also reduces the amount of sediment build-up in the ballast water tanks. The water is finally led to the AOT reactor, which produces radicals and UV light that breaks down and neutralize the organisms.



Ballasting

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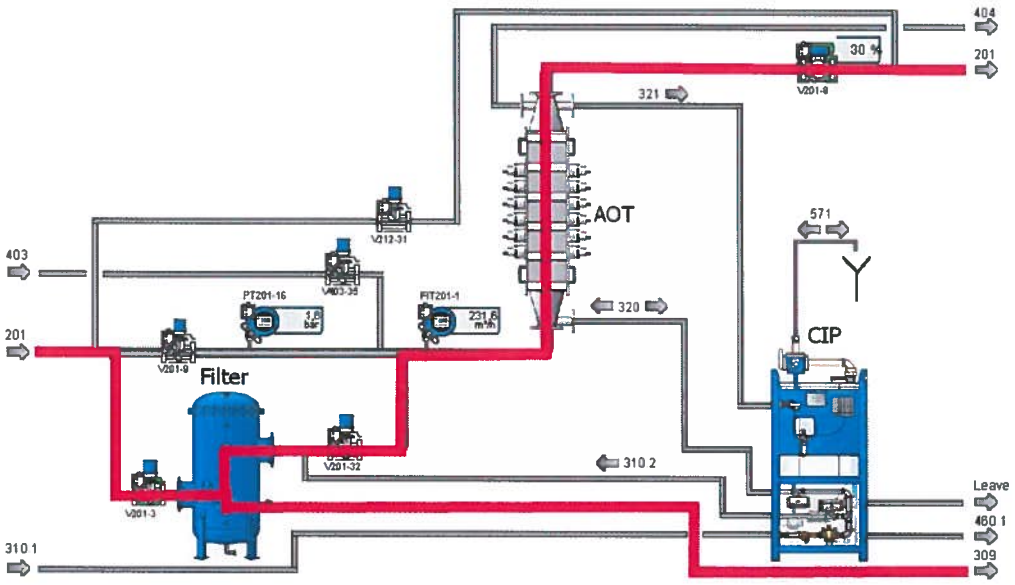
2.2.1 Back-flush

To keep the filter clean, it is automatically back-flushed. The back-flush is performed during ongoing process without interrupting the ballasting process. The water used for back-flushing is returned to the sea directly at the ballasting site.



2 Back flush

Filter back-flush

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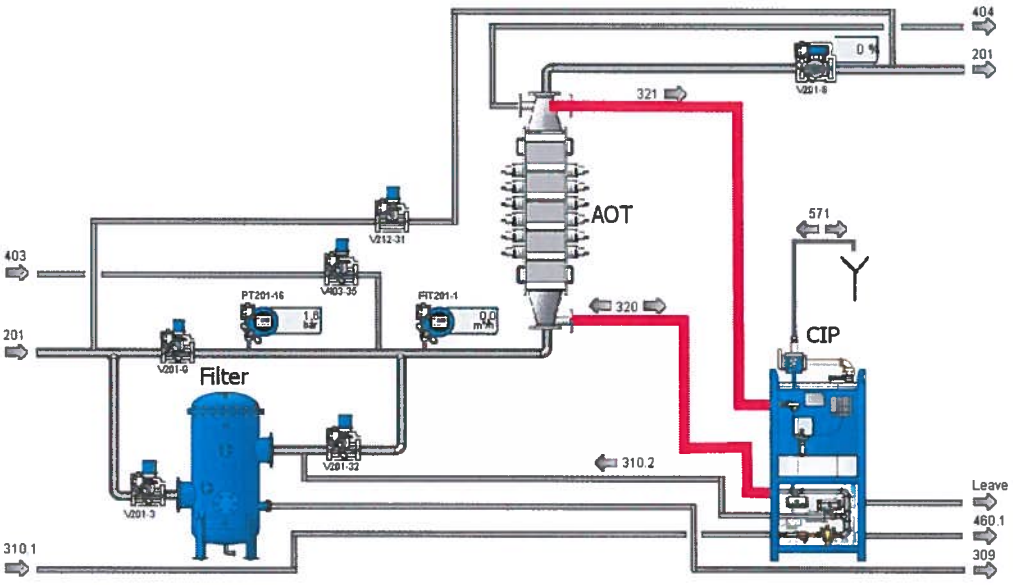
2.2.2 Ballast after-treatment

After every ballast operation, an automatic cleaning cycle is performed to clean the AOT reactor. This cleaning can either be performed immediately after a ballast operation or within 30 hours after. A CIP cycle takes about 15 minutes per AOT. Note, that it is possible to perform processes during these 30 hours.

First, all AOTs are simultaneously rinsed with fresh water. Then the cleaning in place (CIP) module circulates a biodegradable solution through each AOT in sequence to remove seawater scaling. The cleaning liquid is reused between the cleaning operations. After the cleaning is finished all AOTs are filled with fresh water to preserve the filter and prevent scaling, algae growth etc. Also the filter is filled with water for preservation reasons.



Cleaning in place (CIP)

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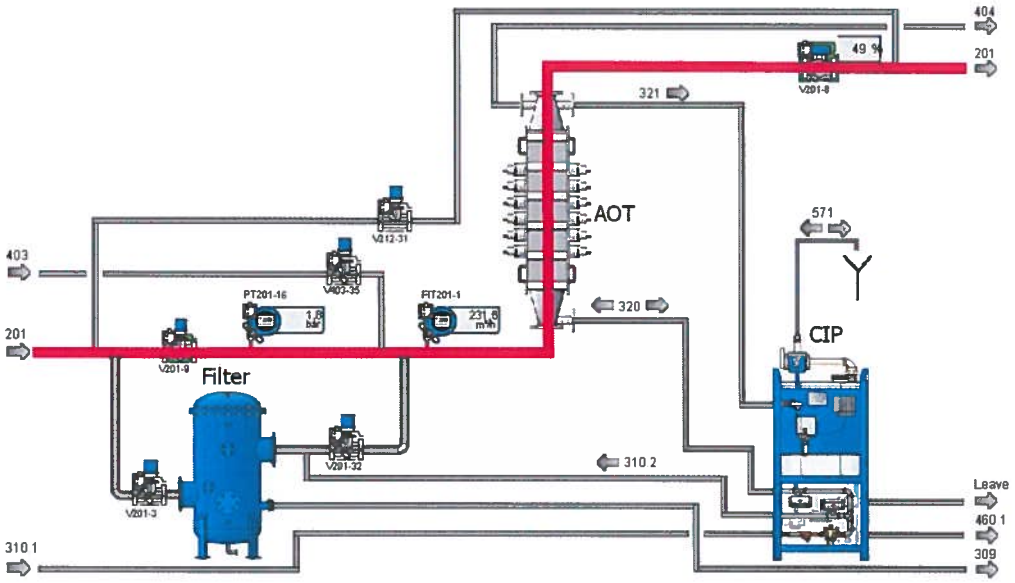
2.3 Deballasting

Deballasting also begins with a ballast start-up to warm the UV lamps. When the actual deballasting process starts, the water passes through the AOT a second time, thus treating the water one more time. The reason for treating the water a second time is to secure that the treatment is fully effective. The minor part of the organisms, which were only injured during ballast, will be rendered totally harmless during the deballast. However, the filter is bypassed since the water has already been filtered.

The process flow is monitored by the flow meter to secure that the flow does not exceed the certified rate and to secure that there is enough flow to cool the UV lamps.



2 FuktDeballast

Deballasting

2.3.1 Deballast after-treatment

After every deballasting operation, an automatic cleaning cycle takes place. It is performed in the same way as described for the ballasting process, but without the filter preservation step, since the filter is not used during deballast.

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2.4 Stripping with eductor

Stripping can be performed to achieve total emptying of the ballast tanks via a stripping eductor. To use PureBallast during a stripping process an eductor must be installed before the PureBallast system.

The water used in the stripping process, must be filtered from particles larger than approximately 5 mm. The water passes through the PureBallast system as a regular deballasting process, but the filter is by-passed. The water is finally pumped into the sea.

Note the following:

- The eductor is not part of Alfa Laval's scope of supply.
- Procedures to dispose of sediments from the sieve must be included in the vessel's ballast water management plan.

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2.5 Ballast water handling in the event of malfunction

PureBallast is equipped with a by-pass valve. The valve can be used in case of emergency to secure the ship, by allowing ballast water operations (ballast, deballast and internal transfers) without involving the ballast water treatment system. The valve is controlled by the ISCS, not PureBallast's control system, but all valve activities are logged in the event log. Such valve is required by the International Convention for the Control and Management of Ship's Ballast Water and Sediments 2004.

If the system malfunction in connection with general cargo operation, ballast and deballast operations should be avoided. In case untreated water is pumped to a ballast tank, this water shall be discharged on open sea (200 NM) and exchanged for treated water. Note that full treatment requires treatment both during ballast and deballast.

The procedures concerning emergency and malfunction of the ballast water treatment system should be implemented in the ships Ballast Water Management Plan.

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3 System components description

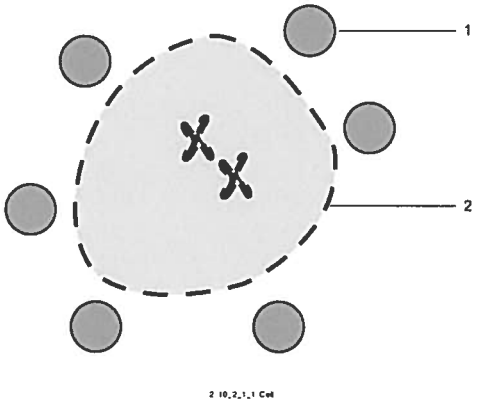
This section gives an introduction to the most important PureBallast system components and their functions in the system.

3.1 AOT module

An AOT module consists of an AOT reactor, a lamp drive cabinet (LDC) and valves at the inlet and outlet of the unit. The LDC does not need to be placed in close relation to the AOT.

3.1.1 AOT working principle

The main treatment process take place inside the AOT reactor, where the UV light inactivates the cell DNA to prevent regrowth of organisms. The UV light also generates radicals. The radicals are extremely reactive and react instantaneously with micro organisms and other organic contaminants destructing their membranes. The radicals are extremely short-lived and exist only for some milliseconds. This means that they will only exist inside the reactor. The quantity of radicals produced in the reactor is sufficient to treat the water as it passes through the reactor.



Destruction of cell membranes

1. *Radical*
2. *Cell membrane*

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There are no chemical substances added to the process, and there are no toxic residuals created. Since the water is not affected chemically there are no environmental impact, and the process does not influence corrosion in any way.

3.1.2 AOT module description

An AOT module consists of an AOT reactor, a lamp drive cabinet (LDC) and valves at the inlet and outlet of the module as shown in the illustration below. The UV lamps are enclosed in individual quartz-glass sleeves. The number and type of lamps differ between the two AOT sizes:

- 300 m^3/h: The AOT reactor accommodates 10 medium-pressure UV lamps (3000 W each).
- 1000 m^3/h: The AOT reactor accommodates 16 medium-pressure UV lamps (6000 W each).

To secure that there is water in the reactor when the lamps are lit, each AOT reactor is equipped with a level switch. The level switch also secures that enough CIP liquid is pumped to the AOT reactor during the CIP cleaning cycle. To secure that the lamps are adequately cooled by the ballast water, each AOT reactor is equipped with one temperature transmitter. The control system monitors theses values and will shut down the AOT if they deviate from parameter set temperature, completed with a temperature switch that automatically shuts down the AOT reactor reaches a too high temperature. UV transmittance in the reactor is monitored by a UV sensor, and the UV lamp power is regulated based on this input. The UV lamp power is regulated between 50 — 100 % of full capacity.

The illustration below show the main components for the AOT reactor. The illustration show an AOT reactor for 300 m^3/h. The 1000 m^3/h contain the same components.

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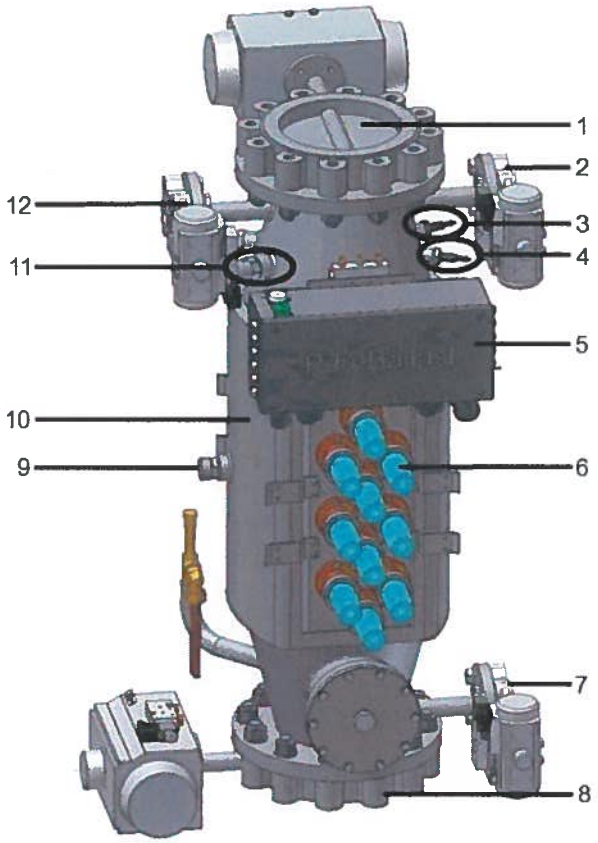

AOT reactor

1. *Ballast water outlet valve*
2. *CIP liquid outlet valve*
3. *Temperature switch*
4. *Temperature transmitter*
5. *Junction box*
6. *UV lamp cap (UV lamp and quartz sleeves inside)*
7. *CIP liquid inlet valve and AOT drain valve*
8. *Ballast water inlet valve*
9. *UV sensor*
10. *AOT reactor*
11. *Level switch*
12. *Cooling water outlet valve*

3.1.3 Lamp drive cabinet (LDC)

An AOT reactor is connected to a lamp drive cabinet (LDC) containing lamp power supplies (LPS). The LPS monitors the function of each UV lamp and takes action if a fault occurs. The LDC can be

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placed up to 200 meters from the AOT reactor. Each LDC is equipped with a main breaker for the AOT. The LDC is equipped with a cooling system to maintain the correct operating temperature in the LDC, using low-temperature cooling water. Cooling is based on input from a temperature transmitter.

Since the two AOT sizes use different UV lamps, the LPS setup in the LDC differs between sizes.

- 300 m^3/h: One LPS supplies power to two UV lamps in the reactor.
- 1000 m^3/h: One LPS supplies power to one UV lamps in the reactor.

3.2 Filter

3.2.1 Filter working principle

The filter is a fully automatic self-rinsing component, equipped with filter elements to remove particles and organisms from the ballast water flow. The ballast water is lead through the filter elements, and filtered particles are trapped in the filter element.

3.2.2 Filter Description

This description is valid for one of the filter types available for installation in PureBallast.

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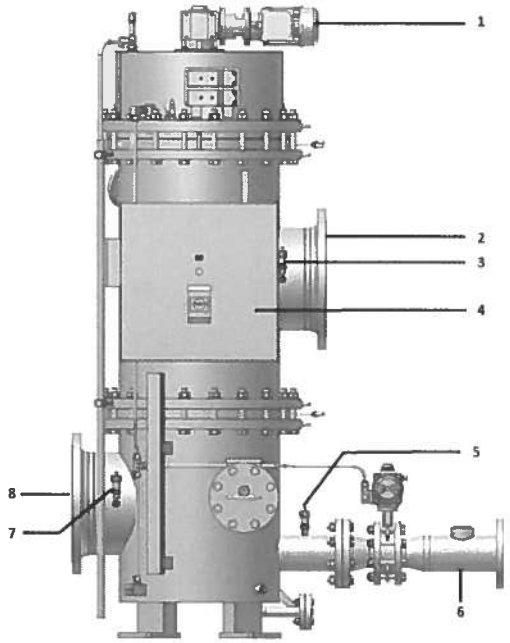

2 Filterhydac

1. *Geared motor*
2. *Water outlet*
3. *Pressure transmitter, outlet*
4. *Filter control cabinet. Only used for connections. The filter is entirely controlled from the PureBallast control system.*
5. *Pressure transmitter, back-flush line*
6. *Back-flush outlet*
7. *Pressure transmitter, inlet*
8. *Water inlet*

To secure efficient filtration, the filter performs a self-rinsing back-flush operation at time set intervals or when triggered by indication of dirt in the filter. Pressure drop over the filter is monitored by pressure transmitters on the the filter inlet and outlet. Dirt is detected by an increased differential pressure drop caused by particles in the filter candles. When the differential pressure reaches a parameter set value, an automatic back-flush operation starts. The back-flushing does not interrupt the filtration process, since the filter candles are cleaned one by one. The other filter candles continue the filtration of the ballast water. It is also possible to start back-flush manually from the control system.

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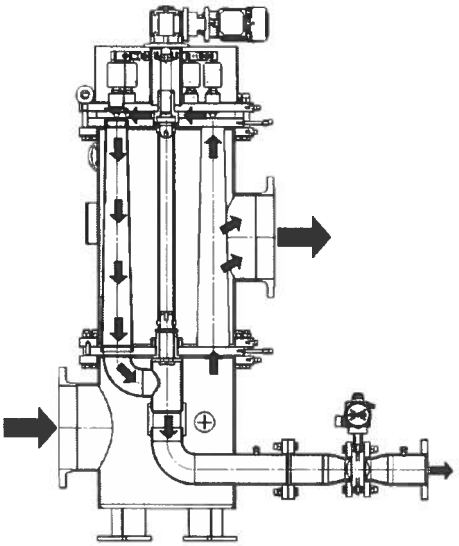
The filter candles are back-flushed in two steps:

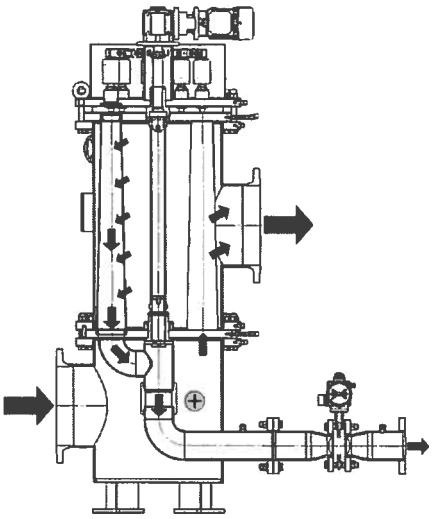
Step 1: The flushing arm is positioned under the first filter candle to be back-flushed. The purpose of the flushing arm is to collect the back-flush water and lead it, with the flushed particles, to the back-flush line. From this point, this filter candle is not used for filtering.

A valve valve on top of the filter candle is opened to lead water through the filter candle from the top downwards. The flow through the filter candle down to the flushing arm, flushes particles from the filter candle walls and lead them to the back-flush line.



Step 2: The valve on top of the filter candle is closed to stop the axial flow to the filter element. The existing water pillar inside the candle continues the flow downwards, which creates an under pressure. This under pressure forces water to flow radial through the filter candle from the outside (filtered side) to the inside (unfiltered side), which pulls remaining particles from the mesh and downwards to the back-flush line.

When the first candle is back-flushed, the flushing arm change position and the process is repeated until all filter candles are rinsed.



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3.3 CIP (cleaning in place) module

3.3.1 CIP working principle

To ensure full performance in PureBallast, an automatic cleaning cycle is performed after every ballast or deballast operation. The purpose is to keep the quartz sleeves covering the UV lamps free from scaling, which otherwise would decreases the efficiency of the AOT.

During a cleaning cycle, the CIP module circulates a CIP liquid through the AOT reactor to remove seawater scaling. After finished cycle, the liquid is returned to the CIP module; the CIP liquid is reusable for a great number of cycles.

3.3.2 CIP module description

The CIP module consists of a tank where the CIP liquid is stored between usage. Before the CIP cycle starts, the AOT is drained from sea water and rinsed with fresh water. When the CIP operation has completed, the CIP module fills the AOT with fresh water. The pumps and valves integrated in the CIP module are controlled by the valve block.

To secure that there is enough CIP liquid for the process, the level switch in the AOT indicates when it is filled with CIP liquid. To prevent intrusion of water in the fresh water system, a backflow preventer is used in the CIP module.

The CIP module is equipped with two membrane pumps:

- Pump P320-1 circulates the CIP liquid to and from the AOT.
- Pump P321-5 drains water (sea and fresh water) overboard from the AOT, via the drain line. The pump is used if the vessel itself is unable to perform the drainage.

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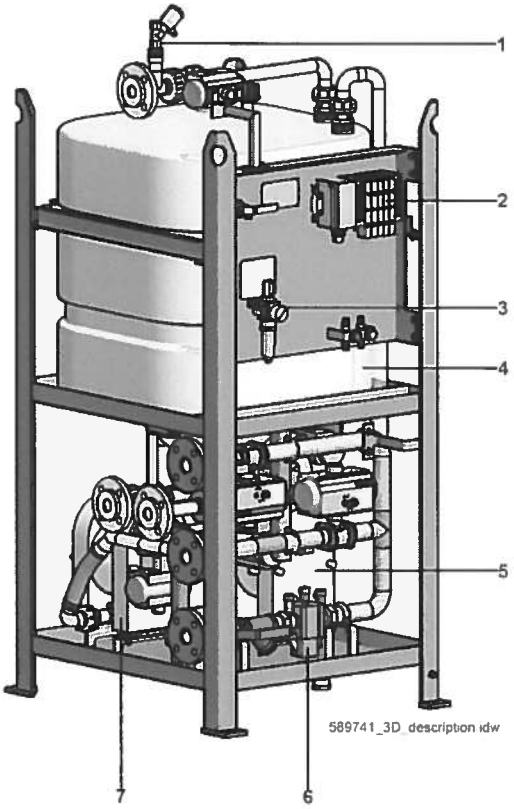

CIP module

1. *Deaeration valve*
2. *Valve block*
3. *Regulator*
4. *Tank for CIP liquid*
5. *Pump (CIP liquid)*
6. *Backflow preventer*
7. *Pump (AOT drain)*

3.4 Flow meter

The flow meter monitors the process-flow during operation. It has two main functions:

- It ensures that the flow within the PureBallast system does not exceed its certified flow rate. If the certified flow is exceeded a warning is issued.
- Via the flow transmitter, mounted on the flow meter, it sends valuable data to the PureBallast control system, where it is displayed. Example of information: Current flow and data about total amount of treated ballast water.

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3.5 Sampling device

The two sampling devices make it possible to take water samples to test the water. One sampling device is installed before the water is treated and one after the water is treated. This enables comparative tests of treated and untreated water.

3.6 Pressure gauge and pressure transmitter

A pressure gauge and a pressure transmitter monitor the pressure in the PureBallast system. Current pressure is analogously displayed on the pressure gauge and electronically sent to the PureBallast control system by the pressure transmitter.

3.7 Main valves

The main valves in the system are:

- **PureBallast bypass valve**: Makes it possible to completely bypass the PureBallast system. The valve is solely operated from the ISCS, but the valve positioning is however indicated in the PureBallast control system. When PureBallast is bypassed, an event is written to the event log.
- **Main inlet and main outlet valve**: Connects the PureBallast system to the vessel's ballast system. The inlet valve directs the water flow into the PureBallast system and the outlet valve returns the water to the vessel's ballast system after treatment.
- **Control valve**: The valve have the following functions:
  - Regulate the flow and pressure to secure that there is enough pressure to perform a back-flush, and that it is maintained.
  - Regulates the process flow so it does not exceed the flow chosen for a process.
  - Main outlet valve.
- **Cooling water inlet valve**: Supplies cooling water to the AOT to protect the lamps from overheating. The valve is common for all installed AOTs.
- **Filter bypass valve**: During deballasting, the water does not pass the filter, since it has already been filtered during ballasting. The bypass valve is used to direct the water flow so that the filter is bypassed.

3.8 Control system

The control system is used to set parameters, operate and monitor the PureBallast system. If two systems is installed on a vessel, two control systems are needed. The control system continuously monitor PureBallast (sensors, communication and PLC status), both during operation and in stand-by mode. Any deviation is either communicated to the operator or handled automatically, based on parameter settings. Safety risks are always handled automatically.

The control system store all relevant events and alarms for at least 24 months. The memory has a vast safety margin but when it is full, data will be deleted starting with the oldest items. Logged information can be exported to a USB memory stick.

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There are three alternative ways to access the control system: Main panel, remote control panel (optional) and remote interface (optional). To avoid double command, PureBallast can only be controlled from one place at a time.

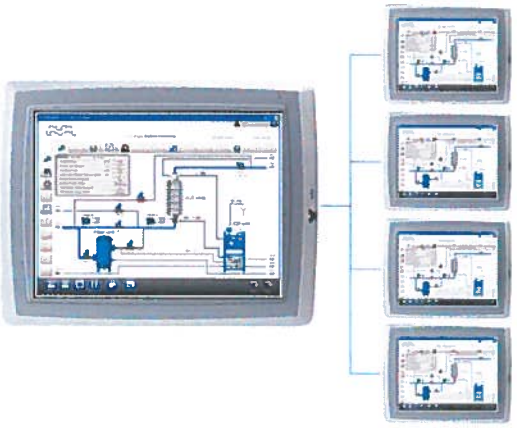
3.8.1 Main control panel

The main control panel is included in the standard installation of PureBallast. It is installed in the engine room. The main control panel handles every aspect of the control system. It allows the operator to monitor the system, to operate it manually and automatically, and to set parameters. Please note that some of the operations are password-protected.

Main control panel

3.8.2 Remote control panel (optional)

It is possible to install 1–4 additional panels as an option to be placed in locations from where ballast operations are performed. A remote control panel looks and functions in the same way as the main control panel, and it allows for the same operations.



Main control panel with four integrated remote control panels.

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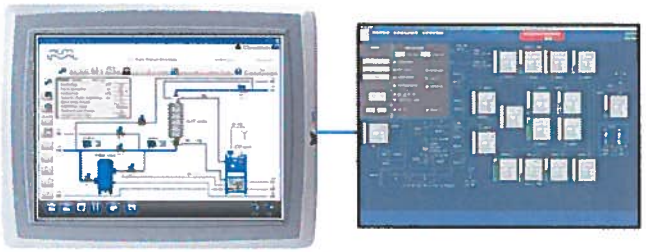
3.8.3 Remote interface (optional)

As an option, the control system can be integrated with the vessel's ISCS via modbus. This allows monitoring and operation of PureBallast from the ISCS's graphical user interface.

Note that Alfa Laval does not supply the graphical user interface to handle PureBallast in the ISCS, only the means to enable the integration.



2 RemoteInterface

PureBallast control system's main control panel integrated with the ISCS. The interface is only an example.

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APPENDIX C

Overview of DHI SOPs

SUBJECT/SUBSUBJECT	DHI SOP NO.
ANALYTICAL METHOD DETERMINATION OF VIABLE ORGANISMS ≥50 µm	30/1700
ANALYTICAL METHOD DETERMINATION OF VIABLE ORGANISMS ≥10 µm AND < 50 µm	30/1701
ANALYTICAL METHOD DETERMINATION OF PRIMARY PRODUCTION OF MICROALGAE	30/1702
ANALYTICAL METHOD DETERMINATION OF VIABLE ALGAE BY RE-GROWTH ASSAY	30/1704
MICROBIOLOGICAL TESTS DETERMINATION OF TOTAL NUMBER OF BACTERIA BY EPIFLUORESCENCE MICROSCOPY	30/1705
MICROBIOLOGICAL TESTS DETERMINATION OF HETEROTROPHIC PLATE COUNT	30/1706
MICROBIOLOGICAL TESTS DETERMINATION OF *VIBRIO CHOLERAE* IN WATER	30/1707
MICROBIOLOGICAL TESTS DETERMINATION OF TOTAL COLIFORM, E.COLI AND ENTEROCOCCI BY Colilert*-18, Enterolert-E or Bio-Rad MUG/MUD kit	30/1708
MEASUREMENT METHOD TRO MEASUREMENT IN WATER	30/1732
HARVESTING, CULTURING AND ADDITION OF ORGANISMS	30/1734
COLLECTION OF SEAWATER	30/1735
COLLECTION OF FRESH WATER	30/1736
CRITERIA FOR TEST WATER ADDITION OF DOC, POC, MM AND BRINE	30/1737
SAMPLING PREPARATION, SUBSAMPLING AND TRANSPORTATION OF SAMPLES	30/1738
DATABASE SAMPLES, LABELS AND DATA SHEETS	30/1750
OPERATION OF THE DHI MTEF	30/1762
CLEANING RETENTION TANKS; PIPINGS AND OTHER EQUIPMENT AT TEST SITE	30/1763
MEASUREMENT METHOD ON-LINE MONITORING OF PRESSURE, TEMPERATURE, FLOW RATES AND QUALITY PARAMETERS AT TEST SITE	30/1764
MEASUREMENT METHOD FLUORESCENCE	30/1765
MEASUREMENT METHOD TURBIDITY	30/1766
DHI MTEF HEALTH AND SAFETY	30/1767
MEASUREMENT METHOD DETERMINATION OF TSS	30/1768
MEASUREMENT METHOD DETERMINATION OF DOC AND POC	30/1769
MEASUREMENT METHOD DETERMINATION OF TRANSMITTANCE	30/1770

AMENDMENT No. 1

Quality Assurance Project Plan

Performance evaluation in land-based test facility. PureBallast. November 2012.

2012.11.20

Amendment comments

Section 1.3 Classification society
The correct address is:
Det Norske Veritas A/S (DNV)
Veritasveien 1
NO-1363 Høvik
Norway

Chapter 2 Project organisation and personnel responsibilities
In Figure 2.1: Project organization, the Administration is Norway, not Denmark.

Section 6.1.1 Source water applied in the land-based test
The organisms that are present in the natural brackish water where the DHI MTEF is situated can also be present in marine water with a higher salinity (>32 PSU). In each BE test cycle, the identified biological species are recorded, making it possible to compare the brackish and marine testing conditions.

Salinity is measured continuously throughout each ballast and de-ballast operation as described in Section 7.1 of the QAPP. These measurements will serve as justification for the tested water type (brackish or marine water).

Comments:
The organisms that are present in marine waters with salinities >32 PSU (or any other water type for that matter) vary tremendously across geographical regions and will thus vary between the land-based test facilities on a global scale. In a specific land-based facility, it is not possible to conduct BE tests on all organisms that may occur in a specific water type.

Section 8.1 Data management
During each ballast and de-ballast operation, the average UV intensity readings (W/m^2) displayed on the PureBallast PLC will be included in the DHI BE test cycle data logging procedures. The UV intensity readings will be included in relevant appendices in the final report.

Section 8.2.4 Physical/chemical analyses
The average flow rate recorded by the DHI online monitoring system is the average flow rate measured before the filter. The average flow rate through the PureBallast AOT reactor will be included in the DHI BE test cycle data logging based on the ballast operation duration and the volume recorded in the retention tank by the DHI online

monitoring system. These calculated flow rates through the PureBallast AOT will be included in relevant appendices in the final report.

DNV also had comments to Appendix B Generic system description. Appendix B was provided by Alfa Laval Tumba AB, and the comments by DNV will be addressed by Alfa Laval Tumba AB in a separate document.

Reason for Amendment

Detailed descriptions or additions requested by DNV after reviewing the QAPP and inspection of PureBallast BE tests at the DHI MTEF.

Impact of Amendment

Additional parameters (UV intensity and calculated average flow rate) included in the DHI BE test cycle data logging.

Preventive action

Not relevant.

Michael Andersen

Michael Andersen

Project manager

2012.11.20

Date

Copy to be sent to the client, the Certification Body and the DHI Quality Assurance Unit.

AMENDMENT No. 2

Quality Assurance Project Plan

Performance evaluation in land-based test facility. PureBallast. October 2012.

2013.02.27

Amendment comments

Additional biological efficacy testing of PureBallast 3.0 to be performed in the spring of 2013 has been requested by Alfa Laval Tumba AB. Two additional test cycles will be performed. The filter type used in the additional test cycles will be decided immediately before additional testing is initiated. One test cycle will be conducted with brackish water and the other with marine water. The water types applied are defined in Section 5.2 of the Quality Assurance Project Plan. The first additional biological efficacy test cycle will be initiated on 7 March 2013.

Reason for Amendment

Two additional test cycles have been requested by DNV to document biological efficacy at total rated capacity.

Impact of Amendment

Two additional biological efficacy test cycles will be conducted. The filter type used will be documented in the DHI BE test cycle data logging.

Preventive action

Not relevant.

Michael Andersen

Michael Andersen

Project manager

2013.02.27

Date

Copy to be sent to the client, the Certification Body and the DHI Quality Assurance Unit.

Revised AMENDMENT No. 2

Quality Assurance Project Plan

Performance evaluation in land-based test facility. PureBallast. October 2012.

2013.03.07

Amendment comments

Additional biological efficacy testing of PureBallast 3.0 to be performed in the spring of 2013 has been requested by Alfa Laval Tumba AB. Two additional test cycles will be performed. One test cycle will be conducted with brackish water and the other with marine water. The water types applied are defined in Section 5.2 of the Quality Assurance Project Plan. The first additional biological efficacy test cycle will be initiated on 8 March 2013.

Reason for Amendment

Two additional test cycles need to be conducted to document biological efficacy at total rated capacity. The two test cycles will also serve as testing of an alternative filter. The filter to be used is a Boll&Kirch 6.18.3, size 250 equipped with 40 µm mesh filter candles.

Impact of Amendment

Two additional biological efficacy test cycles with an alternative filter will be conducted.

Preventive action

Not relevant.

Michael Andersen

Michael Andersen

Project manager

2013.03.07
Date

Copy to be sent to the client, the Certification Body and the DHI Quality Assurance Unit.

APPENDIX B

Adjustments, service and maintenance log for PureBallast 3.0 during land-based testing

Subject	Ref. No	Version	Security	Page
Adjustments, service and maintenance log for PureBallast 3.0 during land-based testing	AW13-107	1		1/4

Department	Date	Issued by
-	2013-09-16	Per Borin

DHI personnel were present during all actions taken. For each action taken Michael Jakob Andersen and/or Flemming Kofoed from DHI were present. Per Borin from AlfaWall was responsible for each action taken.

Date	Actions taken
2012.10.04	**Adjustment of parameters during testing*** Problem: The net flow rate during testing was too low, due to filter back-flushing and that testing aimed to test at a certain flow rate. Actions: To increase the flow rate the following parameters was adjusted: p110: "Certified flow per AOT" – increased the set parameter from 315 m^3/h to 320 m3/h. p111: "Undershoot certified flow" – adjusted the set parameter from 2% to 1%. (This parameter (p111) is a safety marginal between defined maximum flow rate and actual maximum flow rate to ensure maximum flow rate is not exceeded.)
2012.10.11	**Adjustment of parameters during testing*** Problem: The flow rate during testing was still e too low. Actions: To increase the flow rate the following parameters was adjusted: p111: "Undershoot certified flow" - was set to 0% p120: "V201–8 PID proportional gain" – was adjusted from 0,3 to 0,7 p121: "V201–8 PID integral time" - was set to 7.
2012.10.16	**Adjustment of the test equipment** Problem: Because the filter is connected with hoses, which are disconnected after use, the filter has sometimes been dry. This is not good because deposits in the filter dries and accumulate in the filter. The filter should never be dry, which does not occur in a correct installation on ships. The pressure drop across the filter has also increased. Action: Mounted manually operated valves before and after the filter, they are closed before the hoses are disconnected.
2012.10.18	**Alarm A14 "Process flow rate too low during start-up (FIT201-1). Automatic stop"** Problem: Valve V201-19 and V201-20 did not open during start-up. Actions: Adjusted end stop on valve V201-19 - action solved the problem with this valve. Had to remove the actuator on the valve V201-20 and manually open the valve directly on its axis. Because of poorly adjusted end stops, the valve disk pushed too far into the rubber seal and stuck. The valves worked for adjustment and testing could begin.
2012.10.23	**Adjustment of test equipment** Action: Dismantled filter inserts and cleaned them with high-pressure water to remove dried dirt in the filter. This was not performed after the manually operated valves were installed 2012.10.16.
2012.10.24	**Adjustment of test equipment** Problem: Despite cleaned filter inserts (Δp=0,18 bar) the flow rate did not reach over 300 m^3/h. Actions: #1: Removed the hand valve after the filter - flow increased only marginally. #2: Checked valve V201-20; found out that spacer between actuator and valve were incorrectly assembled (2012.10.18) which resulted in valve V201-20 opened only halfway. The flow rate increased well above 300m3/h after correction. #3: Remounted the manual valve after the filter

2012.10.25	**Adjustment of test equipment** Problem: The filter did not clean itself properly; the differential pressure did not recover enough after backflush during start-up. Action: Dismantled filter inserts and cleaned them with high-pressure water before the test was started.
2012.10.29	**Adjustment of test equipment - Filter service by manufacturer.** Participants: Per Borin (Alfa Laval Tumba AB), Jörn Kaiser (HYDAC), Markus Marekyak (HYDAC). Problem: Due to poor filter performance (cleaning ability) Alfa Laval Tumba AB asked the filter supplier HYDAC Process Technology GmbH to check performance and installation on the DHI MTEF. Actions: HYDAC personnel performed the following: 1. Water pumped from sea to sea to see current performance of filter and determine if the installed programme ran as it should. 2. Cleaning of the filter elements as a routine work when a test is done since it is unknown exactly which differential pressure the elements have seen. 3. Change of backflushing line arrangement including reduction of line size from DN80 (original valve) to DN65 (new valve). Target was to reduce the backflushing flow rate. 4. Updating the PLC program to optimize the backflushing cycles and also reduce backflushing water loss due to shorter backflushing cycle. 5. Increased backflush trigger pressure from 0,38 to 0,45 bar. 6. Performed a ballast trial (sea to sea) about half an hour, switched over to prepared water with addotion of TSS, DOC, POC and organisms water (retention tank B1) and continued the ballast trial about one hour. The differential pressure after auto back flush cycle was stabile throughout the test. HYDAC´s comments: a) "The backflushing line arrangement was not optimal. The filter ended at DN100, was reduced to DN80 (information was 3") for about 6 m and then widened to DN100 for appr. 20 m with a slight upswing. Directly behind the filter the bf line went up for appr. 0.5 m. Both (lenght and the height 0.5m) add to additional differential pressure in the backflushing line, which has a negative impact on the flushing efficiency. A shorter BF line would have been desirable. " b) "For an efficient backflushing we require a difference in pressure from inlet to backflushing line of 1 bar during backflushing. At best times during our presence the condition was 0.4 to 0.5 bar. This means there is only little driving force for an efficient backflushing - yet the filter seemed to recover to its initial dp. This low pressure condition is partly due to the fact that the feed line to the filter from the AL system loses appr. 0.7 bar from the system to the inlet of the filter. The displayed pressure (and controlled by the pressure control valve) at the inlet of the system displays eg 2.5 bar while at the filter inlet it is only 1.8 bar."

2012.11.01	**Adjustment of parameters during testing*** Problem: During the start-up the differential pressure over the filter increased to > 1 bar. Actions: 1. Decreased parameter p110 ("Back-flush initial Delay") from 10 seconds to 2 seconds to increase back flush interval. This resulted in conflicting communication between control system and filter. One counter in filter control program is reset if it is ordered to start back flush cycle before current running back flush is ended. Resulting in error in filter program – the back flush arm stopped, back flush valve open, filter alarm positioning error and differential pressure increased to 1.5 bar. 2. Stopped ballast. 3. Set parameter p110 back to 10 seconds and started a ballast cycle. The differential pressure over the filter recovered after some back flush intervals and the test was started. 4. As the pump was running 100% the following parameters were adjusted to keep the flow rate as high as possible: p312: "V201-8 min position during back flush" - was set from 20% to 100% p113: "V201-8 min position during ballas/deballast" - was set from 20% to 50%
2012.11.14	**Adjustment of test equipment** Action: The Hydac RF10 filter was exchanged to a Boll&Kirch 6.18.2 filter for additional biological efficacy testing.
Dec. 2012	**Adjustment of test equipment and software correction** Actions: The PureBallast 3.0 installation was transported to the Alfa Laval office in Sweden for the winter. During the winter break the flow meter was moved from being installed before the filter to being positioned after the filter. A software correction: The processed volume was not accumulated during back flush cycle on the main panel – this was corrected in the software.
2013.02.26	**Re-installation of test equipment** Action: PureBallast 3.0 was re-installed at the DHI MTEF after the winter break. According to agreement with DNV a Boll&Kirch filter 6.18.3 was installed for additional biological efficacy testing. Filter 6.18.3 is the new Boll&Kirch filter and it will replace the earlier model 6.18.2.
2013.03.04	**Sea-to-sea test** Action: Sea-to-sea trial run with Boll&Kirch 6.18.3 to confirm correct installation. No problems observed.
2013.03.06	**Software correction** Action: When software was corrected in December 2012 the special testing feature which made it possible to run the BWMS over total rated capacity TRC (300m^3/h) during testing was removed by mistake – this was corrected again.
2013.03.08	**Adjustment of parameters during testing*** Action: To ensure that the net flow through the system remained above 300m^3/h the following parameters was adjusted: p312: "V201-8 min position during back flush" p113: "V201-8 min position during ballast/deballast"

2013.03.13	**Alarm A29 ”Valve error (V201-8)” during start-up** Problem: The control valve V201-8 is equipped with feed-back signal for closed position (cam-ring that affect a microswitch). The cam ring had dislocated out of position and the valve gave no feedback ”closed”. Action: Cam ring adjusted and secured and the test could be started.
2013.03.14	**Abandoned test due to filter damaged candles** Problem: The filter candles are equipped with a “hydro dynamic” element that divides the filter candle in the middle. This element came loose from several filter elements and fell off and blocked the backwash arm rotation. Bad welding from the manufacturer caused the fail.
2013.03.18	**Adjustment of test equipment** Action: Installed new filter candles in Boll&Kirch 6.18.3 filter, all filter candles were exchanged to new ones. Sea-to-sea trial run afterwards to confirm correct installation. No problems observed.
2013.04.04	**Adjustment of parameters during testing*** Action: To ensure that the net flow rate through the system remained above 300m3/h and that sufficient pressure was available during backwash the following parameters was adjusted: p166: “Pressure PID proportional gain during back flush (Valve V201-8)” - from 0,60 to 0,70 p167: “Pressure PID integral time during back flush (Valve V201-8)” - from 7,0 to 3,0
2013.06.10	**Adjustment of test equipment - see also documents AW13-077** Problem: An unexpected low reduction of organisms at test 2013.03.08/2013.0313 and 2013.04.04/2013.04.09 with respect to influent organism concentration and actual UV transmittance. This in combination with very cold condition (risk of freezing) indicating that contamination has occurred. Action: A test of the by-pass valve V212-31 showed that this valve is leaking water for a long period after operation (ref. doc. AW13-077 *Leakage test by-pass valve 212-31*). Because of the risk of freezing, this valve was opened to drain piping during tests M6 and B7. This had not been done during earlier tests and might have caused the leaking. By-pass valve V212-31 in the test rig was sealed (plugged) and by the following tests reduction of organisms returned to expected levels.

* It should be noted that the program's control algorithm is designed to control the flow rate to stay below the set value (TRC). During the certification tests the requirement is that the flow rate should be at or above the systems TRC. This sometimes requires adjustments of certain parameters depending on the filter loads.

APPENDIX C

Data logging from the biological efficacy testing with PureBallast 3.0

Table C.1 Biological test cycle data logging (B-1)

Subject	Results
Client treatment system	PureBallast 3.0
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)	Reactor: 1 AOT (article number 9002698); 10 medium pressure UV lamps Filter: Hydac RF10-25A-11-PFMNB21-H110; 6 mesh candles 50 µm
Salinity	17 PSU
Retention tank No.	C1
Test cycle No.	B-1
Use of cultured/harvested organisms	Addition backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae
System cleaned before ballast	Yes
Date and time ballast start	2012.10.04 10:40
Date and time ballast stop	2012.10.04 11:23
System pressure during ballast	2.5 bar
Flow rate during ballast	311 m^3/h
Flow rate to ballast tank	307 m^3/h
Power consumption during ballast	23 kWh
UV intensity	312 W/m^2
Treated volume during ballast	217 m^3 + 3 m^3 sampled
Volume used for ballasting	223 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2012.10.09 08:51
Date and time de-ballast stop	2012.10.09 09:29
System pressure during de-ballast	1.2 bar
Flow rate during de-ballast	317 m^3/h
Power consumption during de-ballast	20 kWh
UV intensity	362 W/m^2
Treated volume during de-ballast	201 m^3
General comments/operational issues	Error upon start-up resulting in automatic system stop. Error message: 'AOT fluid level signal missing'. Error caused by air in the system. The system was bled of air and start-up procedure was repeated. Detailed online monitoring data available in enclosed data files.

Table C.2 Onsite measurements (B-1) (standard deviations in parentheses)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Control inlet	101 (±0.20)	8.1 (±0.01)	17 (±0.00)	13 (±0.03)	26 (±0.50)
PureBallast inlet	102 (±0.30)	8.1 (±0.00)	17 (±0.00)	13 (±0.01)	26 (±0.78)
PureBallast treated T0	100 (±1.1)	8.1 (±0.02)	17 (±0.03)	13 (±0.03)	26 (±3.9)
PureBallast before treatment T5	60 (±3.1)	7.6 (±0.05)	17 (±0.02)	12 (±0.14)	8.2 (±0.70)
PureBallast treated discharge	61 (±2.6)	7.5 (±0.05)	17 (±0.02)	12 (±0.14)	7.9 (±7.9)
Control discharge	61 (±2.6)	7.6 (±0.04)	17 (±0.01)	12 (±0.21)	0.46 (±0.20)

PSU Practical salinity units
NTU Nephelometric turbidity units

Table C.3 Biological efficacy test cycle data logging (B-2)

Subject	Results
Client treatment system	PureBallast 3.0
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)	Reactor: 1 AOT (article number 9002698); 10 medium pressure UV lamps Filter: Hydac RF10-25A-11-PFMNB21-H110; 6 mesh candles 50 µm
Salinity	17 PSU
Retention tank No.	B1
Test cycle No.	B-2
Use of cultured/harvested organisms	Addition backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae
System cleaned before ballast	Yes
Date and time ballast start	2012.10.04 12:49
Date and time ballast stop	2012.10.04 13:29
System pressure during ballast	2.6 bar
Flow rate during ballast	323 m^3/h
Flow rate to ballast tank	311 m^3/h
Power consumption during ballast	23 kWh
UV intensity	310 W/m^2
Treated volume during ballast	207 m^3 + 3 m^3 sampled
Volume used for ballasting	218 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2012.10.09 10:14
Date and time de-ballast stop	2012.10.09 10:52
System pressure during de-ballast	1.2 bar
Flow rate during de-ballast	315 m^3/h
Power consumption during de-ballast	20 kWh
UV intensity	356 W/m^2
Treated volume during de-ballast	200 m^3
General comments/operational issues	Detailed online monitoring data available in enclosed data files

Table C.4 Onsite measurements (B-2) (standard deviations in parentheses)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Control inlet	101 (±0.20)	8.1 (±0.01)	17 (±0.00)	13 (±0.03)	26 (±0.50)
PureBallast inlet	102 (±0.05)	8.1 (±0.00)	17 (±0.01)	13 (±0.02)	26 (±0.57)
PureBallast treated T0	100 (±0.39)	8.1 (±0.00)	17 (±0.01)	13 (±0.07)	25 (±1.2)
PureBallast before treatment T5	56 (±3.7)	7.6 (±0.06)	17 (±0.00)	12 (±0.17)	9.1 (±1.7)
PureBallast treated discharge	57 (±4.5)	7.5 (±0.06)	17 (±0.01)	12 (±0.22)	8.1 (±0.47)
Control discharge	61 (±2.6)	7.6 (±0.04)	17 (±0.01)	12 (±0.21)	0.46 (±0.20)

PSU Practical salinity units
NTU Nephelometric turbidity units

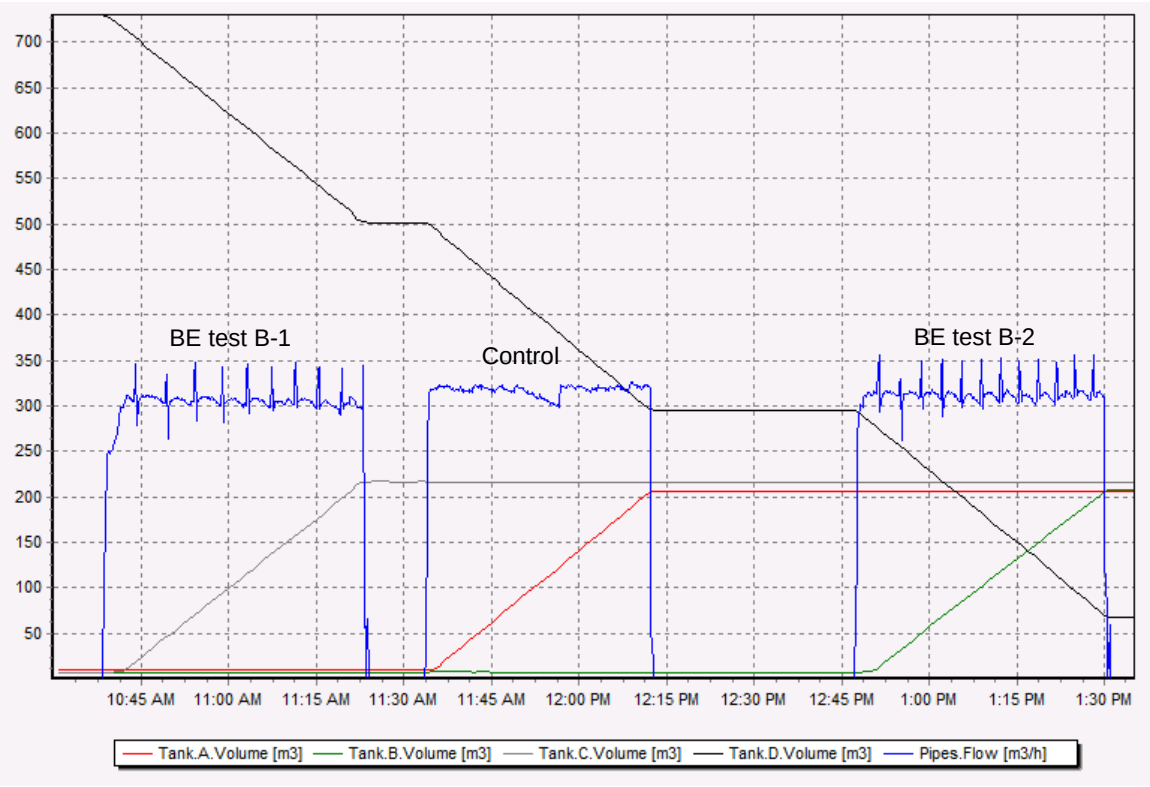

Figure C.1 Biological efficacy test cycles B-1 and B-2 data plot. Ballast operation

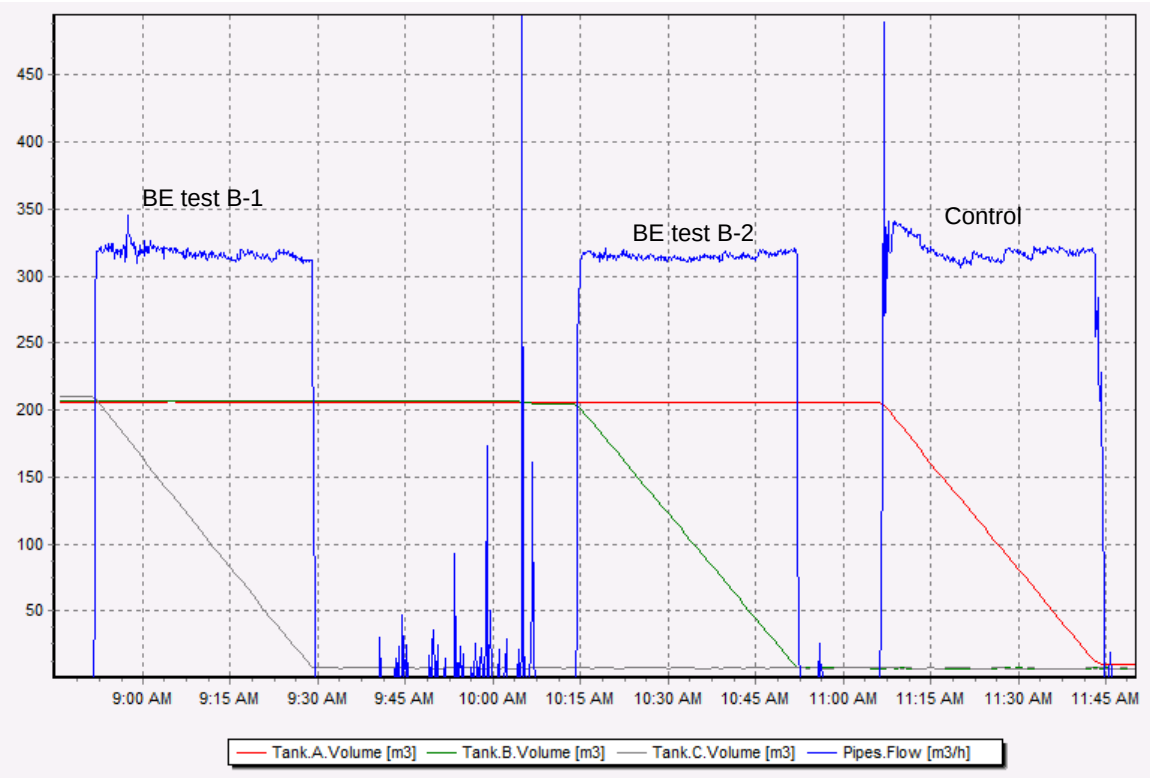

Figure C.2 Biological efficacy test cycles B-1 and B-2 data plot. De-ballast operation

Table C.5 Biological efficacy test cycle data logging (B-3)

Subject	Results
Client treatment system	PureBallast 3.0
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)	Reactor: 1 AOT (article number 9002698); 10 medium pressure UV lamps Filter: Hydac RF10-25A-11-PFMNB21-H110; 6 mesh candles 50 µm
Salinity (PSU)	18
Retention tank No.	C1
Test cycle No.	B-3
Use of cultured/harvested organisms	Addition backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae
System cleaned before ballast	Yes
Date and time ballast start	2012.10.11 09:40
Date and time ballast stop	2012.10.11 10:23
System pressure during ballast	2.6 bar
Flow rate during ballast	324 m^3/h
Flow rate to ballast tank	301 m^3/h
Power consumption during ballast	23 kWh
UV intensity	486 W/m^2
Treated volume during ballast	213 m^3 + 3 m^3 sampled
Volume used for ballasting	232 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2012.10.16 08:29
Date and time de-ballast stop	2012.10.16 09:05
System pressure during de-ballast	1.2 bar
Flow rate during de-ballast	315 m^3/h
Power consumption during de-ballast	18 kWh
UV intensity	528 W/m^2
Treated volume during de-ballast	200 m^3
General comments/operational issues	Detailed online monitoring data available in enclosed data files

Table C.6 Onsite measurements (B-3) (standard deviations in parentheses)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Control inlet	101 (±0.06)	8.2 (±0.00)	18 (±0.00)	10 (±0.02)	33 (±1.4)
PureBallast inlet	101 (±0.51)	8.1 (±0.02)	18 (±0.00)	10 (±0.02)	35 (±2.7)
PureBallast treated T0	100 (±1.2)	8.1 (±0.02)	18 (±0.02)	10 (±0.02)	33 (±3.0)
PureBallast before treatment T5	71 (±1.0)	7.8 (±0.03)	-*	9.7 (±0.01)	14 (±0.24)
PureBallast treated discharge	71 (±1.8)	7.7 (±0.02)	-*	9.8 (±0.01)	12 (±1.1)
Control discharge	73 (±2.3)	7.8 (±0.02)	18 (±0.03)	9.7 (±0.05)	5.2 (±1.0)

* Conductivity probe malfunction
PSU Practical salinity units
NTU Nephelometric turbidity units

Table C.7 Biological efficacy test cycle data logging (B-4)

Subject	Results
Client treatment system	PureBallast 3.0
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)	Reactor: 1 AOT (article number 9002698); 10 medium pressure UV lamps Filter: Hydac RF10-25A-11-PFMNB21-H110; 6 mesh candles 50 µm
Salinity (PSU)	18
Retention tank No.	B1
Test cycle No.	B-4
Use of cultured/harvested organisms	Addition backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae
System cleaned before ballast	Yes
Date and time ballast start	2012.10.11 11:57
Date and time ballast stop	2012.10.11 12:39
System pressure during ballast	2.7 bar
Flow rate during ballast	329 m^3/h
Flow rate to ballast tank	296 m^3/h
Power consumption during ballast	23 kWh
UV intensity	484 W/m^2
Treated volume during ballast	204 m^3 + 3 m^3 sampled
Volume used for ballasting	230 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2012.10.16 10:04
Date and time de-ballast stop	2012.10.16 10:41
System pressure during de-ballast	1.2 bar
Flow rate during de-ballast	315 m^3/h
Power consumption during de-ballast	19 kWh
UV intensity	523 W/m^2
Treated volume during de-ballast	196 m^3
General comments/operational issues	Detailed online monitoring data available in enclosed data files

Table C.8 Onsite measurements (B-4) (standard deviations in parentheses)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Control inlet	101 (±0.06)	8.2 (±0.00)	18 (±0.00)	10 (±0.02)	33 (±1.4)
PureBallast inlet	102 (±0.12)	8.2 (±0.00)	18 (±0.00)	11 (±0.02)	27 (±1.8)
PureBallast treated T0	100 (±0.70)	8.1 (±0.00)	18 (±0.02)	11 (±0.17)	33 (±1.1)
PureBallast before treatment T5	74 (±1.5)	7.9 (±0.03)	-*	9.8 (±0.04)	15 (±1.9)
PureBallast treated discharge	75 (±1.6)	7.8 (±0.03)	18 (±0.00)	9.9 (±0.03)	12 (±0.65)
Control discharge	73 (±2.3)	7.8 (±0.02)	18 (±0.03)	9.7 (±0.05)	5.2 (±1.0)

* Conductivity probe malfunction
PSU Practical salinity units
NTU Nephelometric turbidity units

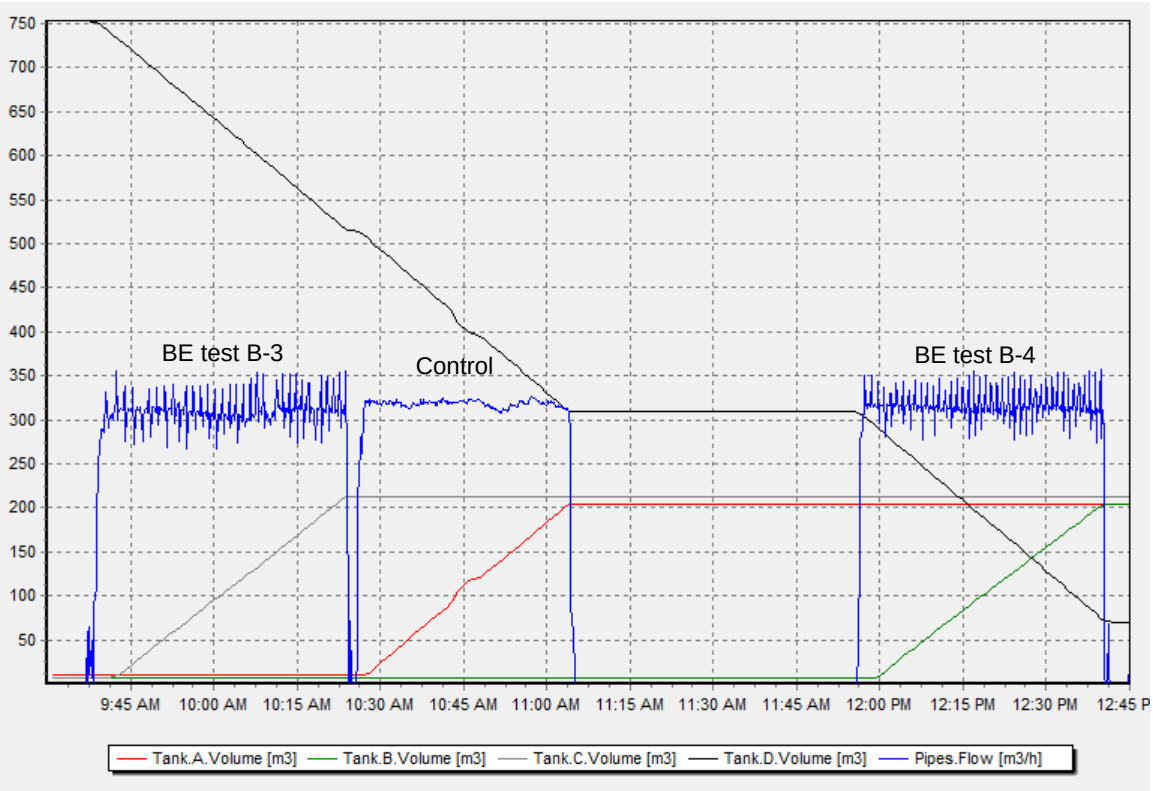

Figure C.3 Biological efficacy test cycles B-3 and B-4 data plot. Ballast operation

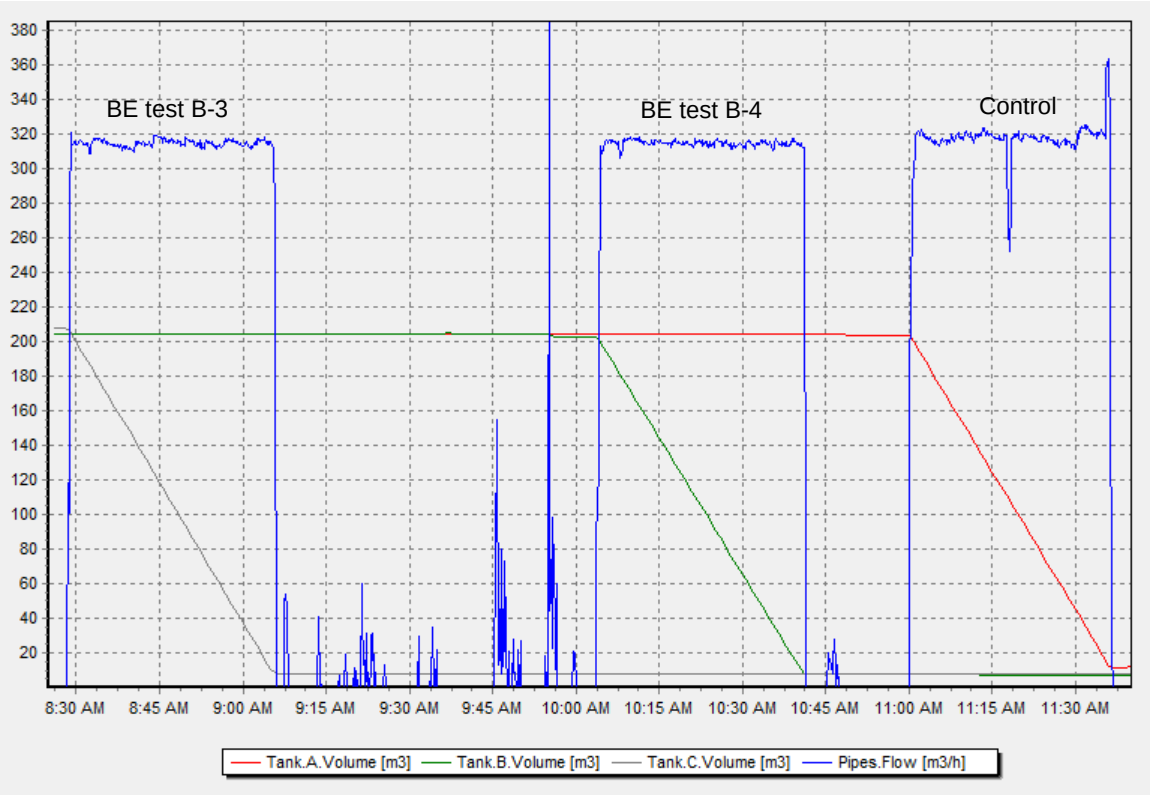

Figure C.4 Biological efficacy test cycles B-3 and B-4 data plot. De-ballast operation

Table C.9 Biological efficacy test cycle data logging (B-5)

Subject	Results
Client treatment system	PureBallast 3.0
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)	Reactor: 1 AOT (article number 9002698); 10 medium pressure UV lamps Filter: Hydac RF10-25A-11-PFMNB21-H110; 6 mesh candles 50 µm
Salinity (PSU)	19
Retention tank No.	C1
Test cycle No.	B-5
Use of cultured/harvested organisms	Addition backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae
System cleaned before ballast	Yes
Date and time ballast start	2012.10.18 09:47
Date and time ballast stop	2012.10.18 10:32
System pressure during ballast	2.8 bar
Flow rate during ballast	312 m^3/h
Flow rate to ballast tank	283 m^3/h
Power consumption during ballast	24 KWh
UV intensity	471 W/m^2
Treated volume during ballast	209 m^3 + 3 m^3 sampled
Volume used for ballasting	234 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2012.10.23 09:07
Date and time de-ballast stop	2012.10.23 09:44
System pressure during de-ballast	1.7 bar
Flow rate during de-ballast	316 m^3/h
Power consumption during de-ballast	20 KWh
UV intensity	507 W/m^2
Treated volume during de-ballast	194 m^3
General comments/operational issues	During system test before ballast operation, PureBallast valve V201-20 did not open. Actuator was removed, valve manually opened and end stops adjusted. On 2012.10.24, it was identified that the spacer between actuator and valve was incorrectly mounted and the valve only half-opened. During the ballast operation, this caused inability to achieve total rated capacity even with the pump operating at full capacity (see Adjustments, service and maintenance log in Appendix B). Detailed online monitoring data available in enclosed data files.

Table C.10 Onsite measurements (B-5) (standard deviations in parentheses)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Control inlet	99 (±0.10)	8.2 (±0.01)	19 (±0.00)	10 (±0.09)	41 (±1.7)
PureBallast inlet	99 (±0.08)	8.1 (±0.01)	19 (±0.00)	10 (±0.01)	43 (±1.1)
PureBallast treated T0	99 (±0.95)	8.0 (±0.02)	19 (±0.10)	10 (±0.06)	37 (±0.92)
PureBallast before treatment T5	82 (±0.99)	7.9 (±0.01)	19 (±0.01)	11 (±0.01)	-*
PureBallast treated discharge	83 (±2.4)	7.8 (±0.02)	19 (±0.01)	11 (±0.01)	11 (±0.28)
Control discharge	83 (±2.8)	7.9 (±0.02)	19 (±0.02)	11 (±0.09)	-*

* Turbidity probe malfunction
PSU Practical salinity units
NTU Nephelometric turbidity units

Table C.11 Biological efficacy test cycle data logging (B-6)

Subject	Results
Client treatment system	PureBallast 3.0
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)	Reactor: 1 AOT (article number 9002698); 10 medium pressure UV lamps Filter: Hydac RF10-25A-11-PFMNB21-H110; 6 mesh candles 50 µm
Salinity (PSU)	19
Retention tank No.	B1
Test cycle No.	B-6
Use of cultured/harvested organisms	Addition backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae
System cleaned before ballast	Yes
Date and time ballast start	2012.10.18 12:08
Date and time ballast stop	2012.10.18 12:54
System pressure during ballast	2.9 bar
Flow rate during ballast	318 m^3/h
Flow rate to ballast tank	277 m^3/h
Power consumption during ballast	26 KWh
UV intensity	477 W/m^2
Treated volume during ballast	209 m^3 + 3m^3 sampled
Volume used for ballasting	244 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2012.10.23 10:27
Date and time de-ballast stop	2012.10.23 11:05
System pressure during de-ballast	1.7 bar
Flow rate during de-ballast	318 m^3/h
Power consumption during de-ballast	19 KWh
UV intensity	508 W/m^2
Treated volume during de-ballast	199 m^3
General comments/operational issues	During system test before ballast operation of BE test B-5, PureBallast valve V201-20 did not open. Actuator was removed, valve manually opened and end stops adjusted. On 2012.10.24, it was identified that the spacer between actuator and valve was incorrectly mounted, and the valve only half-opened. During the ballast operation, this caused inability to achieve total rated capacity even with the pump operating at full capacity (see Adjustments, service and maintenance log in Appendix B). Detailed online monitoring data available in enclosed data files.

Table C.12 Onsite measurements (B-6) (standard deviations in parentheses)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Control inlet	99 (±0.10)	8.2 (±0.01)	19 (±0.00)	10 (±0.09)	41 (±1.7)
PureBallast inlet	100 (±0.24)	8.2 (±0.01)	19 (±0.00)	10 (±0.02)	43 (±0.72)
PureBallast treated T0	100 (±0.17)	8.1 (±0.01)	19 (±0.01)	11 (±0.01)	32 (±0.72)
PureBallast before treatment T5	78 (±3.4)	7.9 (±0.05)	19 (±0.01)	11 (±0.08)	-*
PureBallast treated discharge	79 (±3.2)	7.8 (±0.06)	19 (±0.00)	11 (±0.07)	11 (±0.50)
Control discharge	83 (±2.8)	7.9 (±0.02)	19 (±0.02)	11 (±0.09)	-*

* Turbidity probe malfunction
PSU Practical salinity units
NTU Nephelometric turbidity units

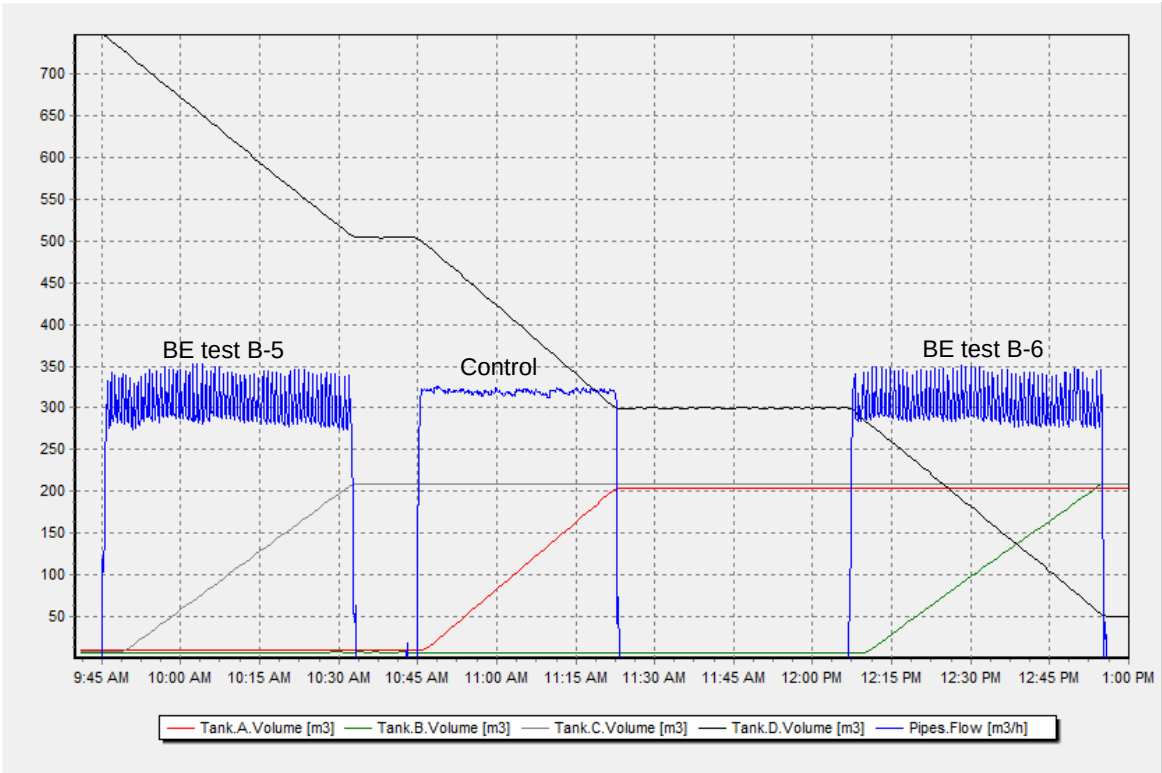

Figure C.5 Biological efficacy test cycles B-5 and B-6 data plot. Ballast operation

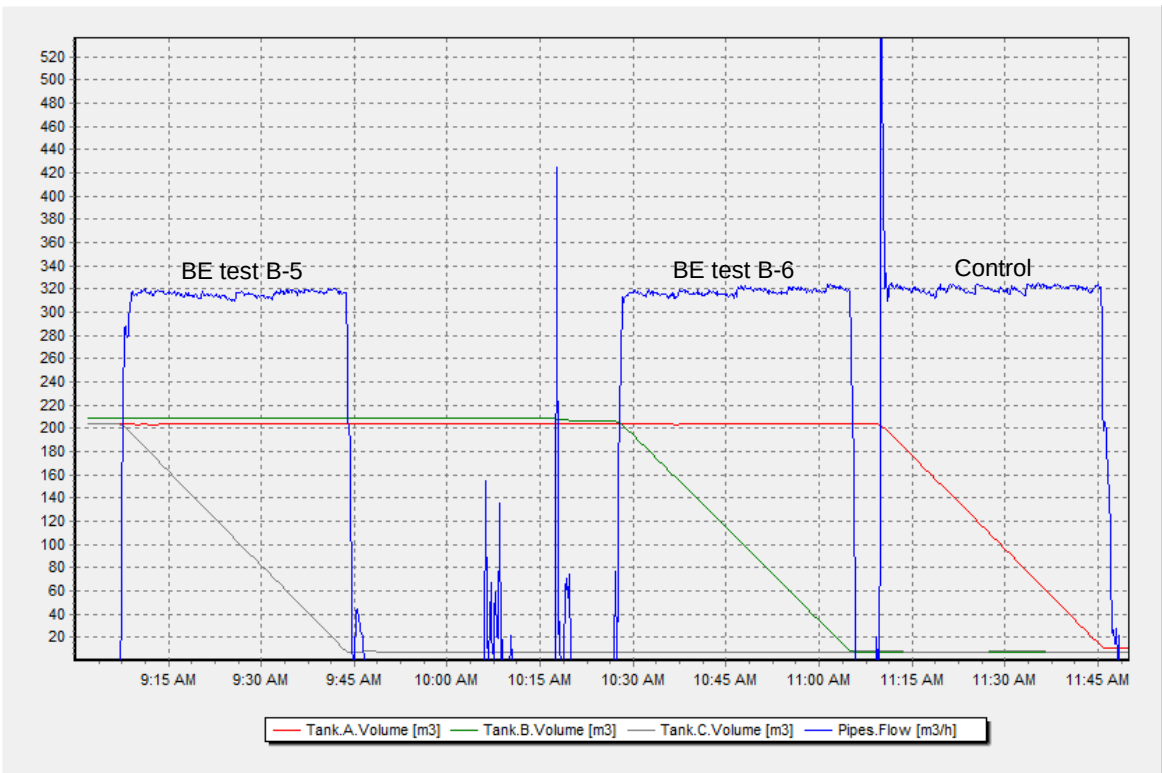

Figure C.6 Biological efficacy test cycles B-5 and B-6 data plot. De-ballast operation

Table C.13 Biological efficacy test cycle data logging (B-7)

Subject	Results
Client treatment system	PureBallast 3.0
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)	Reactor: 1 AOT (article number 9002698); 10 medium pressure UV lamps Filter: Boll & Kirch 6.18.3 BWT DN 250; 16 mesh candles 40 µm
Salinity (PSU)	18
Retention tank No.	B1
Test cycle No.	B-7
Use of cultured/harvested organisms	Addition backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae
System cleaned before ballast	Yes
Date and time ballast start	2013.03.08 10:07
Date and time ballast stop	2013.03.08 10:48
System pressure during ballast	1.8 bar
Flow rate during ballast	328 m^3/h
Flow rate to ballast tank	306 m^3/h
Power consumption during ballast	24 kWh
UV intensity	487 W/m^2
Treated volume during ballast	206 m^3 + 3 m^3 sampled
Volume used for ballasting	224 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.03.13 11:03
Date and time de-ballast stop	2012.03.13 11:41
System pressure during de-ballast	1.4 bar
Flow rate during de-ballast	305 m^3/h
Power consumption during de-ballast	19 kWh
UV intensity	577 W/m^2
Treated volume during de-ballast	194 m^3
General comments/operational issues	-

Table C.14 Onsite measurements (B-7) (standard deviations in parentheses)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Control inlet	106 (±0.25)	8.0 (±0.00)	18 (±0.00)	1.4 (±0.01)	30 (±0.42)
PureBallast inlet	106 (±0.08)	7.9 (±0.00)	18 (±0.00)	1.4 (±0.01)	30 (±0.34)
PureBallast treated T0	106 (±0.46)	7.7 (±0.01)	18 (±0.07)	1.5 (±0.01)	29 (±0.47)
PureBallast before treatment T5	102 (±0.29)	8.0 (±0.00)	18 (±0.01)	0.69 (±0.07)	10 (±0.24)
PureBallast treated discharge	101 (±0.32)	7.7 (±0.00)	18 (±0.34)	0.71 (±0.11)	10 (±0.30)
Control discharge	98 (±0.72)	7.9 (±0.01)	18 (±0.00)	0.83 (±0.28)	6.2 (±1.5)

PSU Practical salinity units
NTU Nephelometric turbidity units

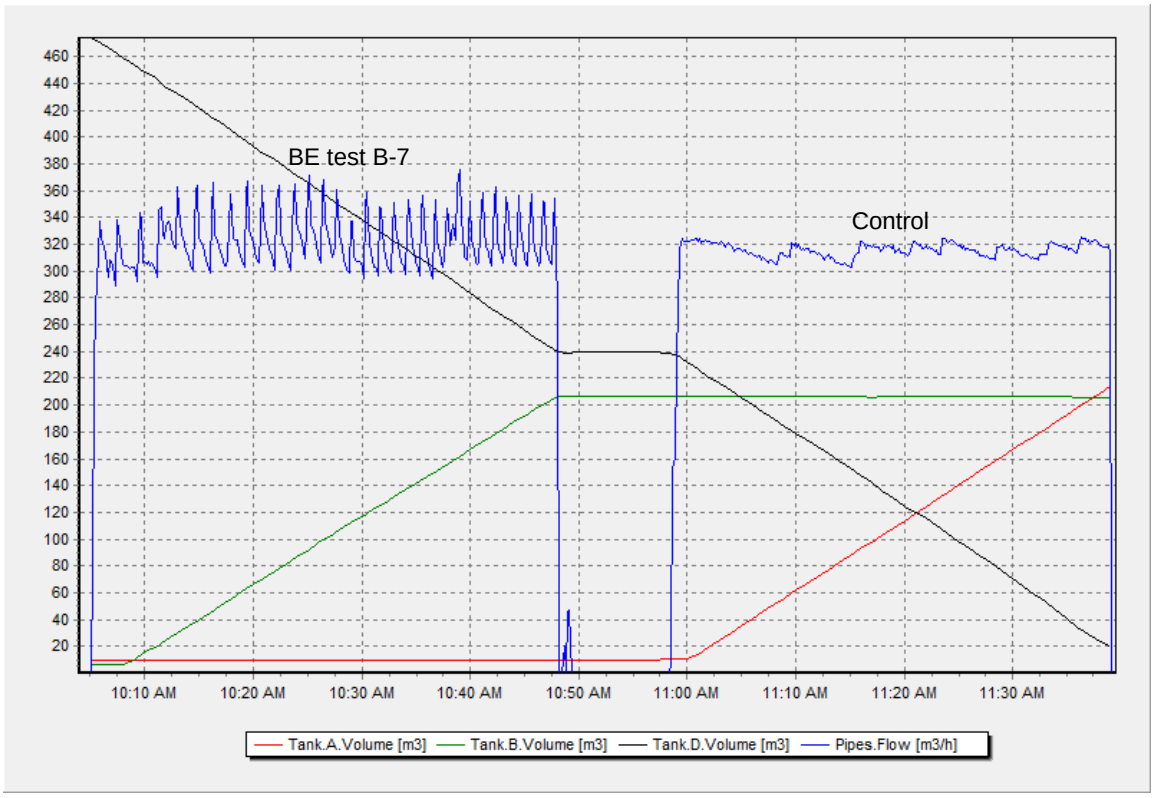

Figure C.7 Biological efficacy test cycle B-7 data plot. Ballast operation

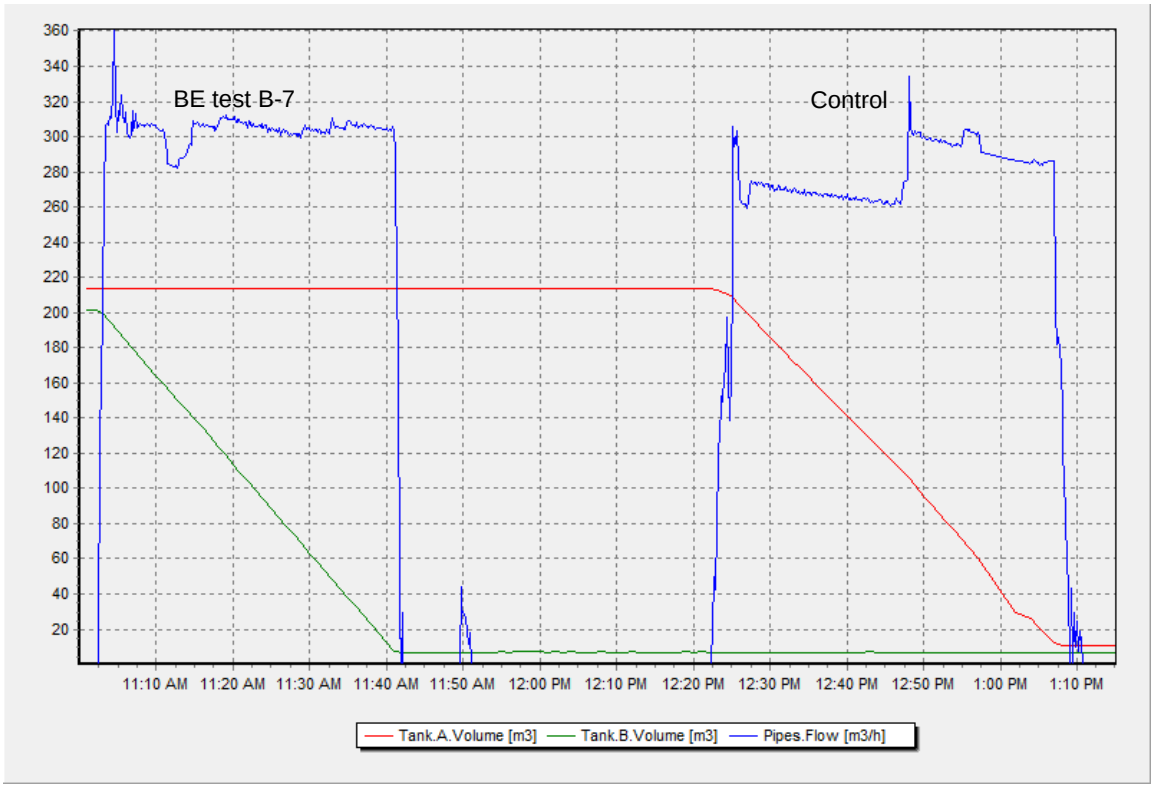

Figure C.8 Biological efficacy test cycle B-7 data plot. De-ballast operation

Table C.15 Biological efficacy test cycle data logging (M-1)

Subject	Results
Client treatment system	PureBallast 3.0
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)	Reactor: 1 AOT (article number 9002698); 10 medium pressure UV lamps Filter: Hydac RF10-25A-11-PFMNB21-H110; 6 mesh candles 50 µm
Salinity (PSU)	34
Retention tank No.	C1
Test cycle No.	M-1
Use of cultured/harvested organisms	Addition backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae
System cleaned before ballast	Yes
Date and time ballast start	2012.10.25 13:29
Date and time ballast stop	2012.10.25 14:10
System pressure during ballast	2.8 bar
Flow rate during ballast	342 m^3/h
Flow rate to ballast tank	300 m^3/h
Power consumption during ballast	22 kWh
UV intensity	421 W/m^2
Treated volume during ballast	202 m^3 + 3 m^3 sampled
Volume used for ballasting	234 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2012.10.30 09:41
Date and time de-ballast stop	2012.10.30 10:16
System pressure during ballast	1.2 bar
Flow rate during de-ballast	317 m^3/h
Power consumption during de-ballast	18 kWh
UV intensity	464 W/m^2
Treated volume during de-ballast	189 m^3
General comments/operational issues	Detailed online monitoring data available in enclosed data files

Table C.16 Onsite measurements (M-1) (standard deviations in parentheses)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Control inlet	99 (±0.17)	8.0 (±0.00)	34 (±0.00)	10 (±0.01)	22 (±0.24)
PureBallast inlet	99 (±0.49)	8.0 (±0.00)	34 (±0.00)	10 (±0.17)	23 (±1.6)
PureBallast treated T0	98 (±0.14)	7.9 (±0.02)	34 (±0.01)	11 (±0.01)	22 (±0.56)
PureBallast before treatment T5	74 (±1.5)	7.7 (±0.02)	34 (±0.03)	7.6 (±0.05)	10 (±1.6)
PureBallast treated discharge	73 (±1.1)	7.6 (±0.02)	34 (±0.01)	7.6 (±0.04)	10 (±2.7)
Control discharge	63 (±1.4)	7.6 (±0.01)	34 (±0.03)	8.0 (±0.22)	2.7 (±0.52)

PSU Practical salinity units
NTU Nephelometric turbidity units

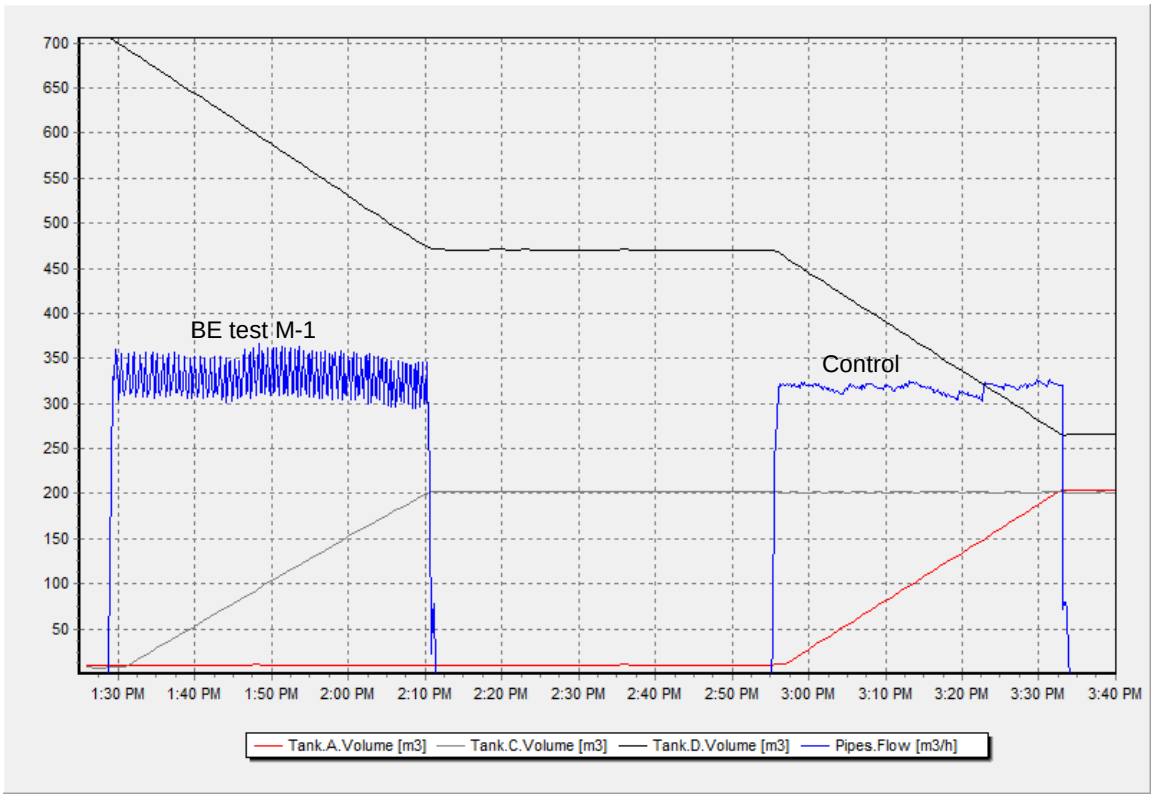

Figure C.9 Biological efficacy test cycle M-1 data plot. Ballast operation

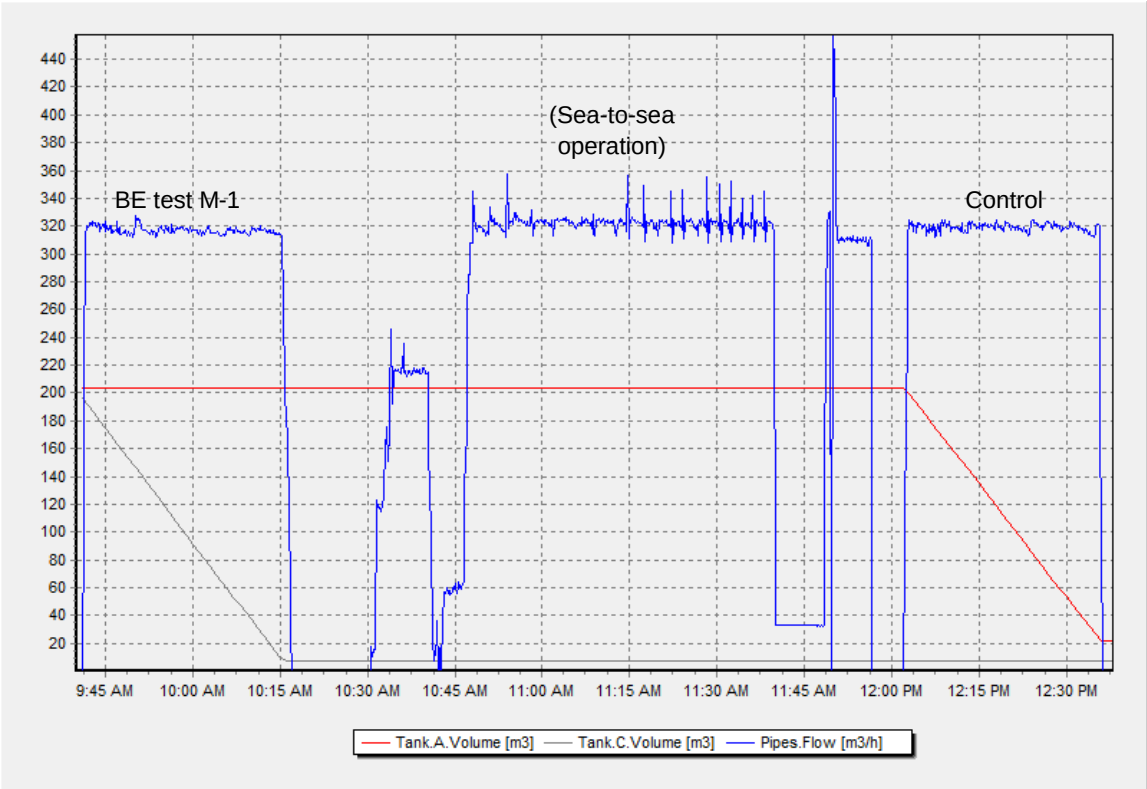

Figure C.10 Biological efficacy test cycle M-1 data plot. De-ballast operation

Table C.17 Biological efficacy test cycle data logging (M-2)

Subject	Results
Client treatment system	PureBallast 3.0
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)	Reactor: 1 AOT (article number 9002698); 10 medium pressure UV lamps Filter: Hydac RF10-25A-11-PFMNB21-H110; 6 mesh candles 50 µm
Salinity (PSU)	32
Retention tank No.	C1
Test cycle No.	M-2
Use of cultured/harvested organisms	Addition backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae
System cleaned before ballast	Yes
Date and time ballast start	2012.11.01 12:04
Date and time ballast stop	2012.11.01 12:46
System pressure during ballast	3.0 bar
Flow rate during ballast	344 m^3/h
Flow rate to ballast tank	301 m^3/h
Power consumption during ballast	23 kWh
UV intensity	470 W/m^2
Treated volume during ballast	208 m^3 + 3 m^3 sampled
Volume used for ballasting	241 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2012.11.06 08:40
Date and time de-ballast stop	2012.11.06 09:16
System pressure during de-ballast	1.2 bar
Flow rate during de-ballast	316 m^3/h
Power consumption during de-ballast	20 kWh
UV intensity	495 W/m^2
Treated volume during de-ballast	195 m^3
General comments/operational issues	Error after start-up of ballast operation. Due to incorrect software setting, the valve on the filter backwash flange was blocked in open position resulting in too high differential pressure. PureBallast was shut down. Settings were adjusted (see Adjustments, service and maintenance log in Appendix B) and ballast operation restarted. Detailed online monitoring data available in enclosed data files.

Table C.18 Onsite measurements (M-2) (standard deviations in parentheses)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Control inlet	93 (±0.05)	8.0 (±0.00)	32 (±0.00)	7.0 (±0.01)	25 (±1.3)
PureBallast inlet	93 (±0.07)	8.0 (±0.00)	32 (±0.00)	7.0 (±0.01)	25 (±0.27)
PureBallast treated T0	93 (±0.39)	7.8 (±0.01)	32 (±0.01)	7.1 (±0.00)	25 (±5.1)
PureBallast before treatment T5	76 (±0.93)	7.7 (±0.02)	32 (±0.03)	6.8 (±0.00)	11 (±0.89)
PureBallast treated discharge	75 (±0.24)	7.5 (±0.01)	32 (±0.01)	6.8 (±0.01)	11 (±1.2)
Control discharge	66 (±1.6)	7.6 (±0.01)	32 (±0.02)	7.1 (±0.18)	2.8 (±0.58)

PSU Practical salinity units
NTU Nephelometric turbidity units

Table C.19 Biological efficacy test cycle data logging (M-3)

Subject	Results
Client treatment system	PureBallast 3.0
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)	Reactor: 1 AOT (article number 9002698); 10 medium pressure UV lamps Filter: Hydac RF10-25A-11-PFMNB21-H110; 6 mesh candles 50 µm
Salinity (PSU)	32
Retention tank No.	B1
Test cycle No.	M-3
Use of cultured/harvested organisms	Addition backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae
System cleaned before ballast	Yes
Date and time ballast start	2012.11.01 14:01
Date and time ballast stop	2012.11.01 14:42
System pressure during ballast	3.0 bar
Flow rate during ballast	350 m^3/h
Flow rate to ballast tank	303 m^3/h
Power consumption during ballast	23 kWh
UV intensity	470 W/m^2
Treated volume during ballast	204 m^3 + 3 m^3 sampled
Volume used for ballasting	239 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2012.11.06 10:08
Date and time de-ballast stop	2012.11.06 10:45
System pressure during de-ballast	1.3 bar
Flow rate during de-ballast	318 m^3/h
Power consumption during de-ballast	19 kWh
UV intensity	494 W/m^2
Treated volume during de-ballast	195 m^3
General comments/operational issues	Detailed online monitoring data available in enclosed data files

Table C.20 Onsite measurements (M-3) (standard deviations in parentheses)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Control inlet	93 (±0.05)	8.0 (±0.00)	32 (±0.00)	7.0 (±0.01)	25 (±1.3)
PureBallast inlet	93 (±0.69)	8.0 (±0.00)	32 (±0.00)	7.1 (±0.01)	26 (±0.71)
PureBallast treated T0	93 (±0.93)	7.8 (±0.00)	32 (±0.01)	7.1 (±0.01)	22 (±0.65)
PureBallast before treatment T5	76 (±2.0)	7.7 (±0.00)	32 (±0.04)	6.9 (±0.07)	11 (±1.8)
PureBallast treated discharge	76 (±1.1)	7.6 (±0.00)	32 (±0.01)	6.9 (±0.05)	11 (±0.92)
Control discharge	66 (±1.6)	7.6 (±0.01)	32 (±0.02)	7.1 (±0.18)	2.8 (±0.58)

PSU Practical salinity units
NTU Nephelometric turbidity units

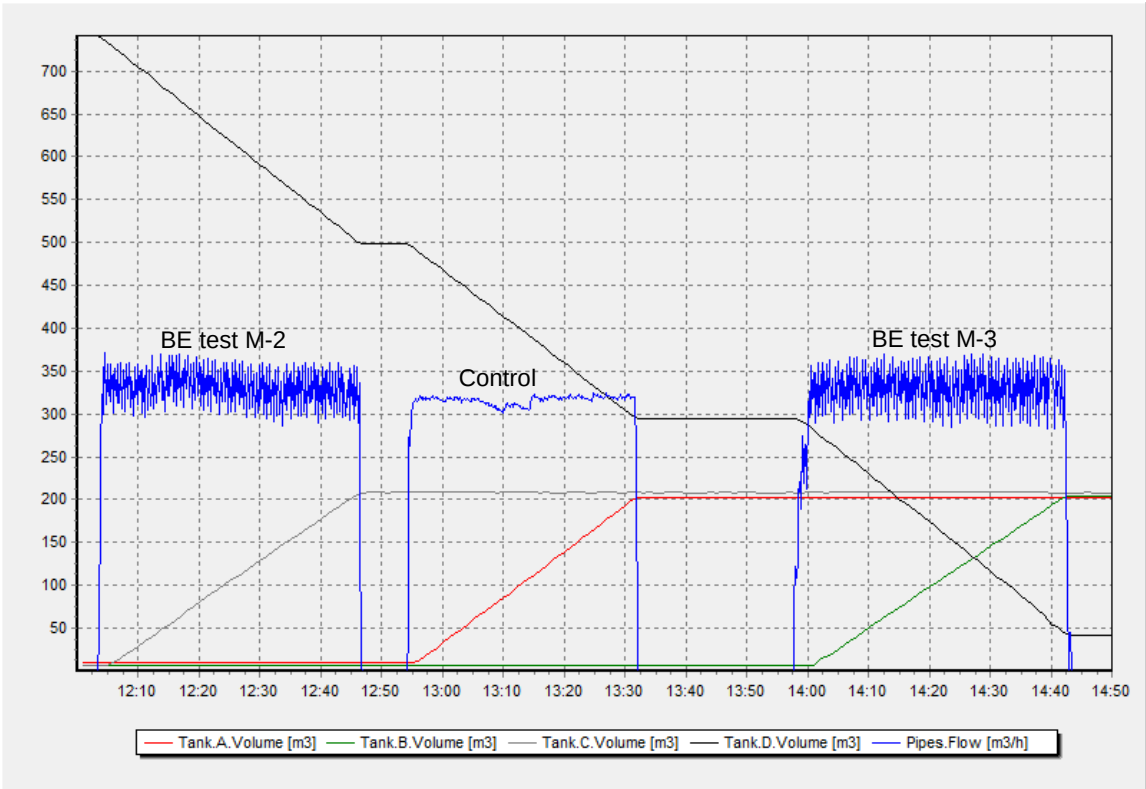

Figure C.11 Biological efficacy test cycles M-2 and M-3 data plot. Ballast operation

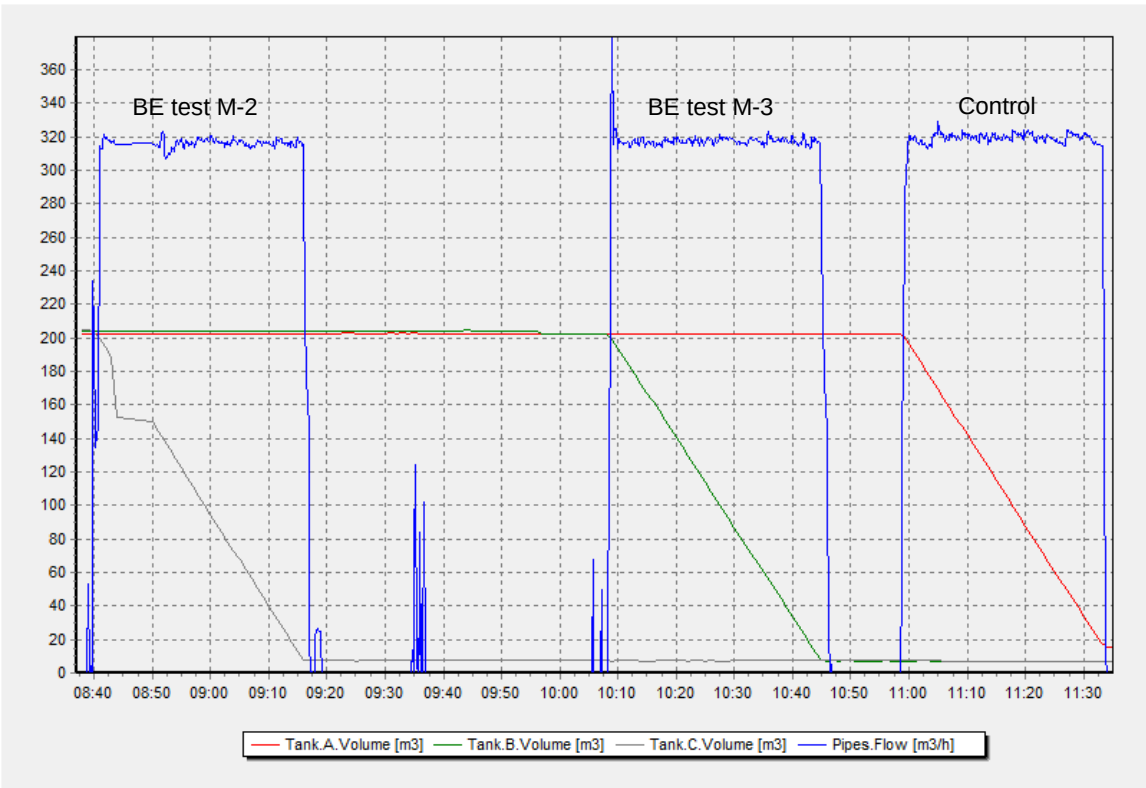

Figure C.12 Biological efficacy test cycles M-2 and M-3 data plot. De-ballast operation

Table C.21 Biological efficacy test cycle data logging (M-4)

Subject	Results
Client treatment system	PureBallast 3.0
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)	Reactor: 1 AOT (article number 9002698); 10 medium pressure UV lamps Filter: Hydac RF10-25A-11-PFMNB21-H110; 6 mesh candles 50 µm
Salinity (PSU)	36
Retention tank No.	C1
Test cycle No.	M-4
Use of cultured/harvested organisms	Addition backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae
System cleaned before ballast	Yes
Date and time ballast start	2012.11.08 10:08
Date and time ballast stop	2012.11.08 10:54
System pressure during ballast	3.4 bar
Flow rate during ballast	317 m^3/h
Flow rate to ballast tank	280 m^3/h
Power consumption during ballast	26 kWh
UV intensity	459 W/m^2
Treated volume during ballast	212 m^3 + 3 m^3 sampled
Volume used for ballasting	243 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2012.11.13 08:48
Date and time de-ballast stop	2012.11.13 09:24
System pressure during de-ballast	1.2 bar
Flow rate during de-ballast	318 m^3/h
Power consumption during de-ballast	20 kWh
UV intensity	500 W/m^2
Treated volume during de-ballast	199 m^3
General comments/operational issues	Detailed online monitoring data available in enclosed data files

Table C.22 Onsite measurements (M-4) (standard deviations in parentheses)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Control inlet	91 (±0.05)	7.9 (±0.00)	36 (±0.00)	7.7 (±0.01)	24 (±0.78)
PureBallast inlet	91 (±0.81)	7.9 (±0.01)	36 (±0.02)	7.7 (±0.03)	25 (±1.7)
PureBallast treated T0	91 (±1.3)	7.7 (±0.01)	36 (±0.02)	7.8 (±0.01)	25 (±3.9)
PureBallast before treatment T5	67 (±1.6)	7.5 (±0.04)	36 (±0.01)	7.8 (±0.05)	11 (±4.0)
PureBallast treated discharge	68 (±1.6)	7.4 (±0.04)	36 (±0.01)	7.8 (±0.05)	10 (±2.0)
Control discharge	63 (±4.5)	7.5 (±0.05)	36 (±0.02)	8.0 (±0.09)	4.2 (±2.2)

PSU Practical salinity units
NTU Nephelometric turbidity units

Table C.23 Biological efficacy test cycle data logging (M-5)

Subject	Results
Client treatment system	PureBallast 3.0
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)	Reactor: 1 AOT (article number 9002698); 10 medium pressure UV lamps Filter: Hydac RF10-25A-11-PFMNB21-H110; 6 mesh candles 50 µm
Salinity (PSU)	36
Retention tank No.	B1
Test cycle No.	M-5
Use of cultured/harvested organisms	Addition backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae
System cleaned before ballast	Yes
Date and time ballast start	2012.11.08 12:41
Date and time ballast stop	2012.11.08 13:31
System pressure during ballast	3.4 bar
Flow rate during ballast	304 m^3/h
Flow rate to ballast tank	250 m^3/h
Power consumption during ballast	26 kWh
UV intensity	459 W/m^2
Treated volume during ballast	205 m^3 + 3 m^3 sampled
Volume used for ballasting	253 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2012.11.13 10:34
Date and time de-ballast stop	2012.11.13 11:11
System pressure during de-ballast	1.2 bar
Flow rate during de-ballast	317 m^3/h
Power consumption during de-ballast	19 kWh
UV intensity	491 W/m^2
Treated volume during de-ballast	195 m^3
General comments/operational issues	Ballast operation: Remote control of ballast pump disconnected at 13:01 resulting in decreased flow rate for approx. one minute. Detailed online monitoring data available in enclosed data files.

Table C.24 Onsite measurements (M-5) (standard deviations in parentheses)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Control inlet	91 (±0.05)	7.9 (±0.00)	36 (±0.00)	7.7 (±0.01)	24 (±0.78)
PureBallast inlet	92 (±1.1)	7.9 (±0.00)	36 (±0.01)	7.9 (±0.02)	25 (±0.81)
PureBallast treated T0	92 (±1.9)	7.8 (±0.00)	36 (±0.03)	7.9 (±0.02)	28 (±7.5)
PureBallast before treatment T5	69 (±1.6)	7.6 (±0.01)	36 (±0.02)	7.9 (±0.05)	10 (±0.94)
PureBallast treated discharge	69 (±1.4)	7.4 (±0.01)	36 (±0.01)	8.0 (±0.04)	11 (±1.3)
Control discharge	63 (±4.5)	7.5 (±0.05)	36 (±0.02)	8.0 (±0.09)	4.2 (±2.2)

PSU Practical salinity units
NTU Nephelometric turbidity units

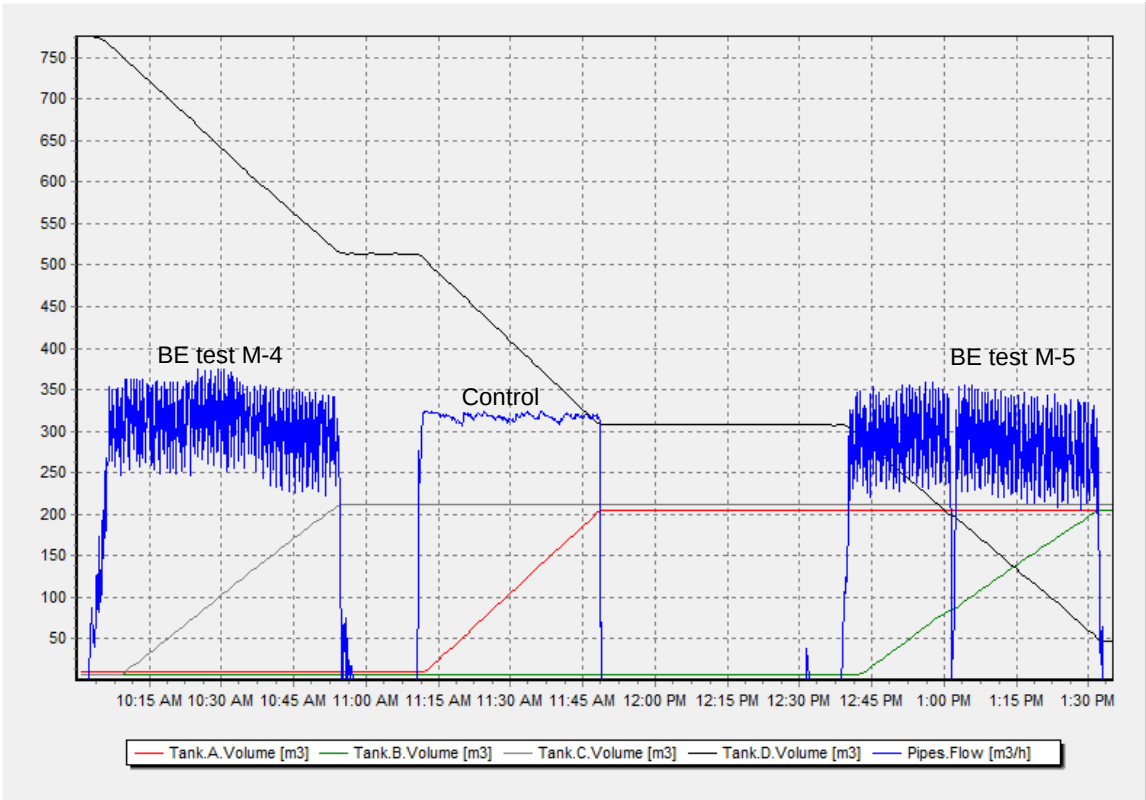

Figure C.13 Biological efficacy test cycles M-4 and M-5 data plot. Ballast operation

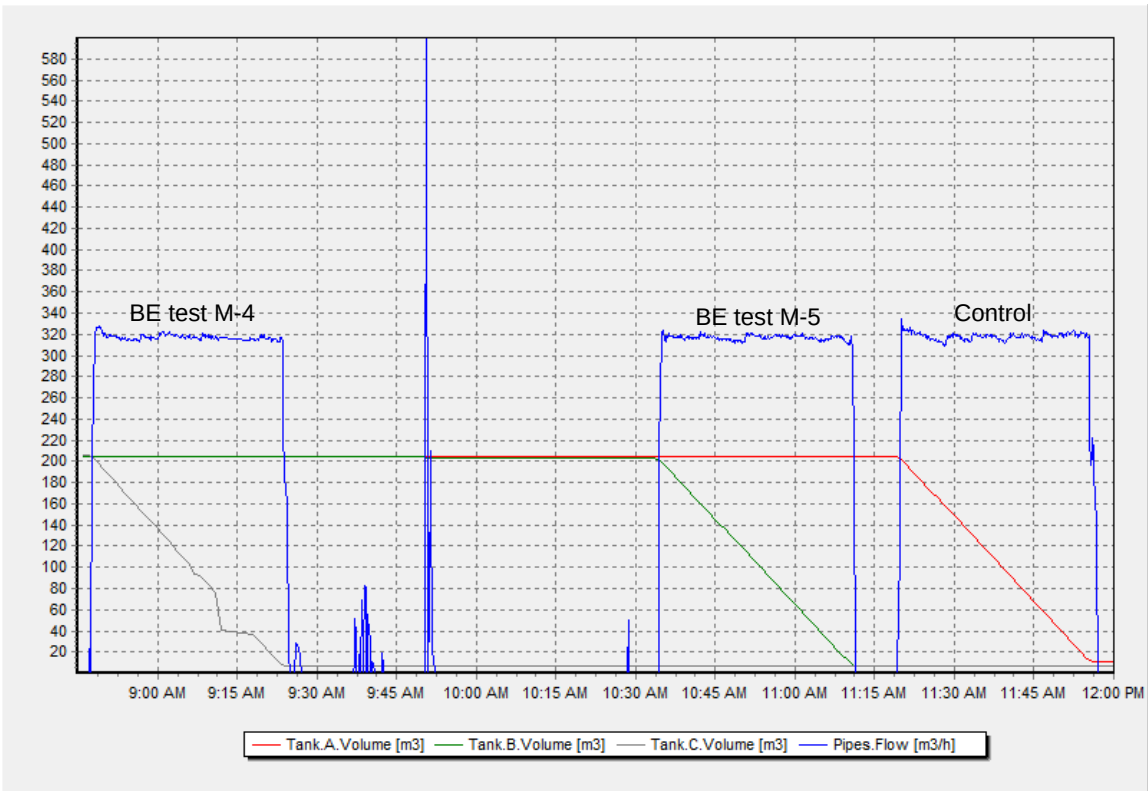

Figure C.14 Biological efficacy test cycles M-4 and M-5 data plot. De-ballast operation

Table C.25 Biological efficacy test cycle data logging (M-6)

Subject	Results
Client treatment system	PureBallast 3.0
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)	Reactor: 1 AOT (article number 9002698); 10 medium pressure UV lamps Filter: Boll & Kirch 6.18.3 BWT DN 250; 16 mesh candles 40 µm
Salinity (PSU)	33
Retention tank No.	B1
Test cycle No.	M-6
Use of cultured/harvested organisms	Addition backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae
System cleaned before ballast	Yes
Date and time ballast start	2013.04.04 10:33
Date and time ballast stop	2013.04.04 11:14
System pressure during ballast	2.9 bar
Flow rate during ballast	378 m^3/h
Flow rate to ballast tank	317 m^3/h
Power consumption during ballast	22 kWh
UV intensity	425 W/m^2
Treated volume during ballast	208 m^3 + 3 m^3 sampled
Volume used for ballasting	252 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.04.09 09:02
Date and time de-ballast stop	2013.04.09 09:40
System pressure during de-ballast	Not measured, pressure sensor malfunction
Flow rate during de-ballast	313 m^3/h
Power consumption during de-ballast	21 kWh
UV intensity	452 W/m^2
Treated volume during de-ballast	197 m^3
General comments/operational issues	-

Table C.26 Onsite measurements (M-6) (standard deviations in parentheses)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Control inlet	117 (±1.6)	7.8 (±0.00)	33 (±0.02)	3.3 (±0.04)	23 (±2.1)
PureBallast inlet	118 (±0.09)	7.8 (±0.00)	33 (±0.00)	3.2 (±0.02)	22 (±0.31)
PureBallast treated T0	118 (±0.89)	7.9 (±0.00)	33 (±0.00)	3.3 (±0.02)	22 (±0.75)
PureBallast before treatment T5	99 (±0.72)	7.5 (±0.01)	33 (±0.20)	4.4 (±0.35)	12 (±1.9)
PureBallast treated discharge	101 (±1.4)	7.6 (±0.01)	33 (±0.01)	4.6 (±0.32)	13 (±1.9)
Control discharge	100 (±0.51)	7.6 (±0.01)	33 (±0.11)	4.9 (±0.55)	5.1 (±0.41)

PSU Practical salinity units
NTU Nephelometric turbidity units

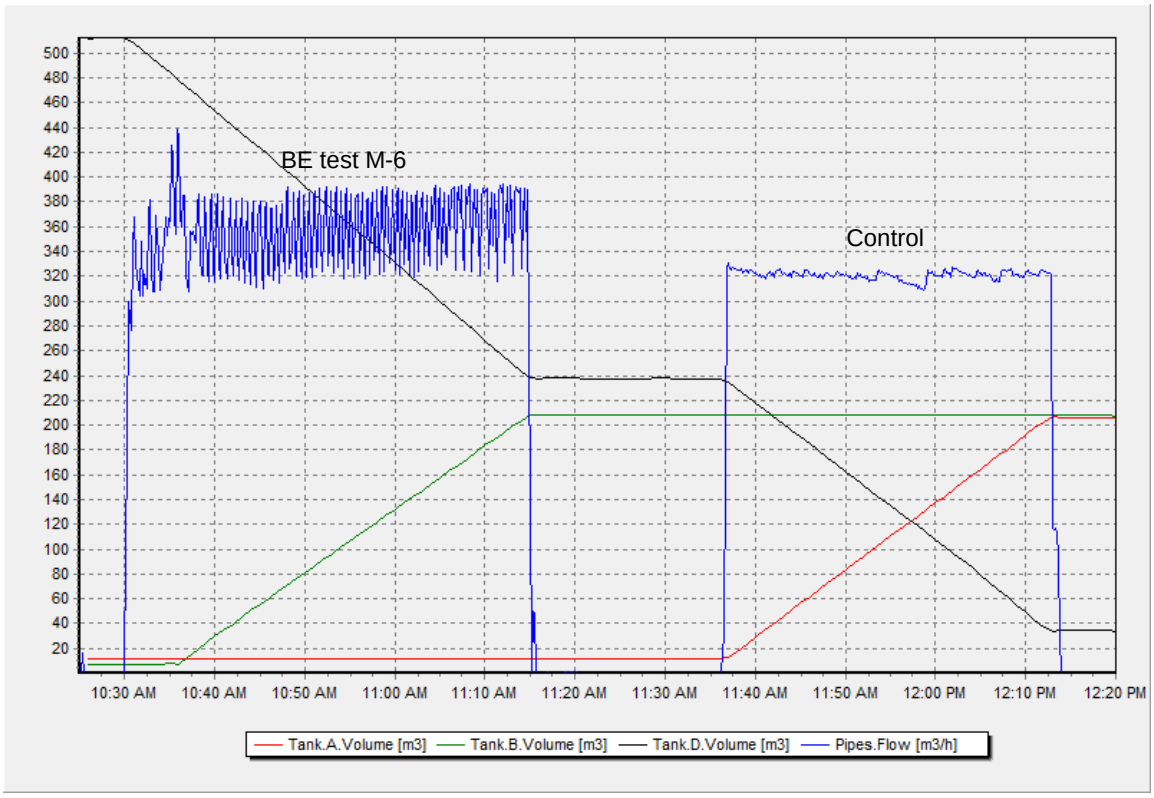

Figure C.14 Biological efficacy test cycle M-6 data plot. Ballast operation

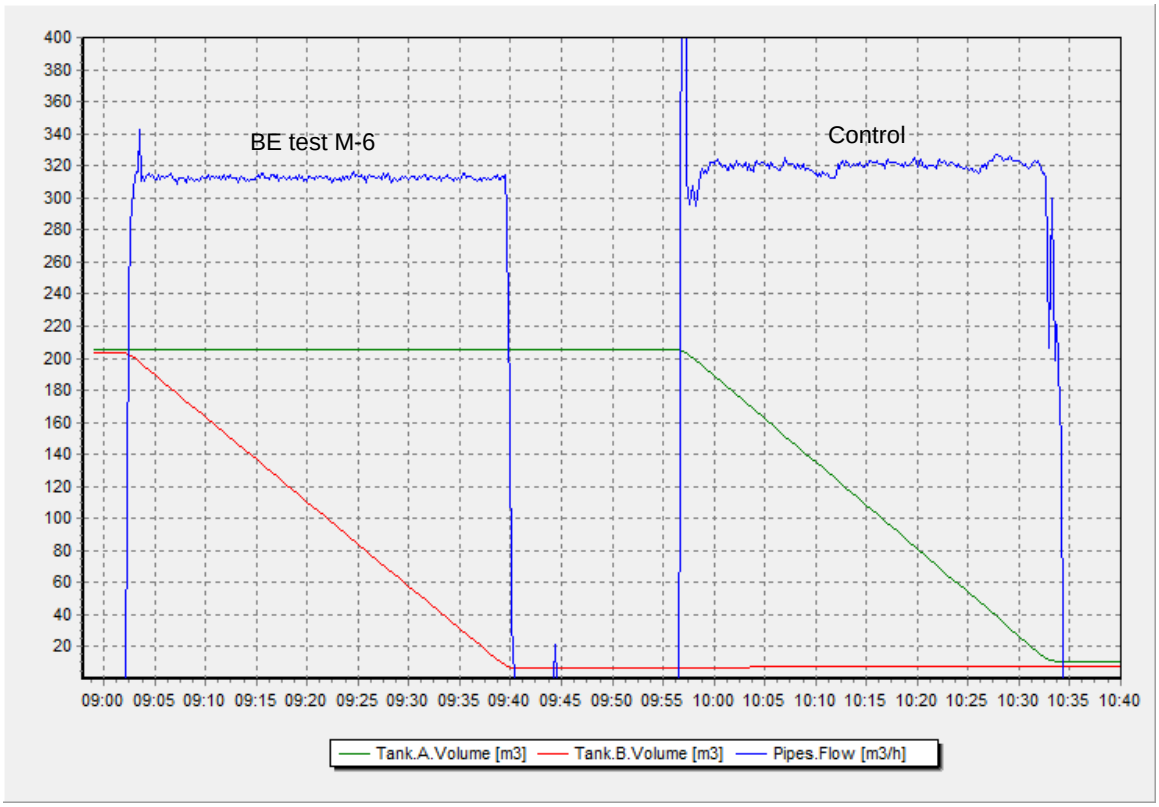

Figure C.15 Biological efficacy test cycle M-6 data plot. De-ballast operation

Table C.27 Biological efficacy test cycle data logging (M-7)

Subject	Results
Client treatment system	PureBallast 3.0
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)	Reactor: 1 AOT (article number 9002698); 10 medium pressure UV lamps Filter: Boll & Kirch 6.18.3 BWT DN 250; 16 mesh candles 40 µm
Salinity (PSU)	34
Retention tank No.	C1
Test cycle No.	M-7
Use of cultured/harvested organisms	Addition of backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae
System cleaned before ballast	Yes
Date and time ballast start	2013.06.13 09:54
Date and time ballast stop	2013.06.13 10:35
System pressure during ballast	2.5 bar
Flow rate during ballast	375 m^3/h
Flow rate to ballast tank	310 m^3/h
Power consumption during ballast	22 kWh
UV intensity	467 W/m^2
Treated volume during ballast	209 m^3 + 3 m^3
Volume used for ballasting	256 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.06.18 10:47
Date and time de-ballast stop	2013.06.18 11:24
System pressure during de-ballast	1.5 bar
Flow rate during de-ballast	313 m^3/h
Power consumption during de-ballast	23 kWh
UV intensity	565 W/m^2
Treated volume during de-ballast	197 m^3
General comments/operational issues	-

Table C.28 Onsite measurements (M-7) (standard deviations in parentheses)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Control inlet	99 (±0.14)	8.1 (±0.00)	34 (±0.00)	18 (±0.02)	34 (±0.85)
PureBallast inlet	101 (±0.23)	8.1 (±0.01)	34 (±0.00)	18 (±0.01)	35 (±0.43)
PureBallast treated T0	101 (±0.33)	8.0 (±0.01)	34 (±0.01)	18 (±0.01)	33 (±0.87)
PureBallast before treatment T5	61 (±2.0)	7.7 (±0.02)	34 (±0.00)	17 (±0.36)	7.9 (±0.78)
PureBallast treated discharge	62 (±1.1)	7.6 (±0.03)	34 (±0.01)	17 (±0.33)	7.9 (±0.46)
Control discharge	47 (±4.3)	7.5 (±0.05)	34 (±0.07)	18 (±0.50)	1.1 (±0.61)

PSU Practical salinity units
NTU Nephelometric turbidity units

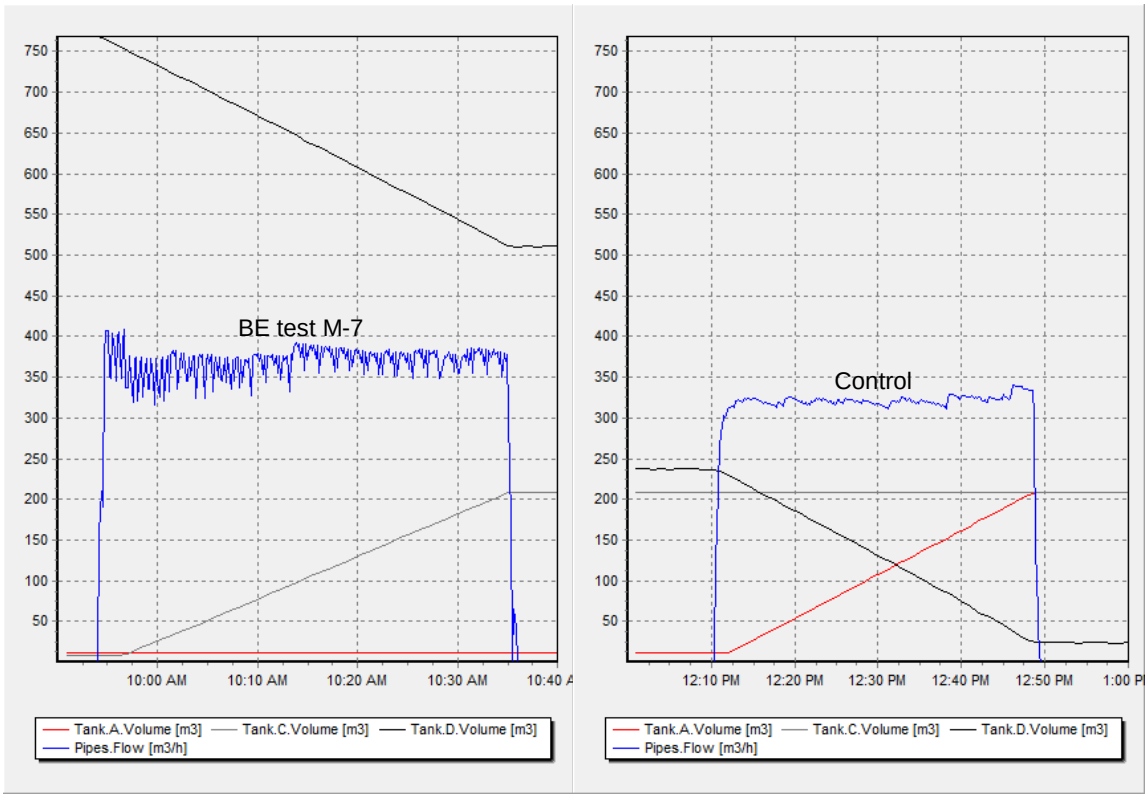

Figure C.16 Biological efficacy test cycle M-7 data plot. Ballast operation

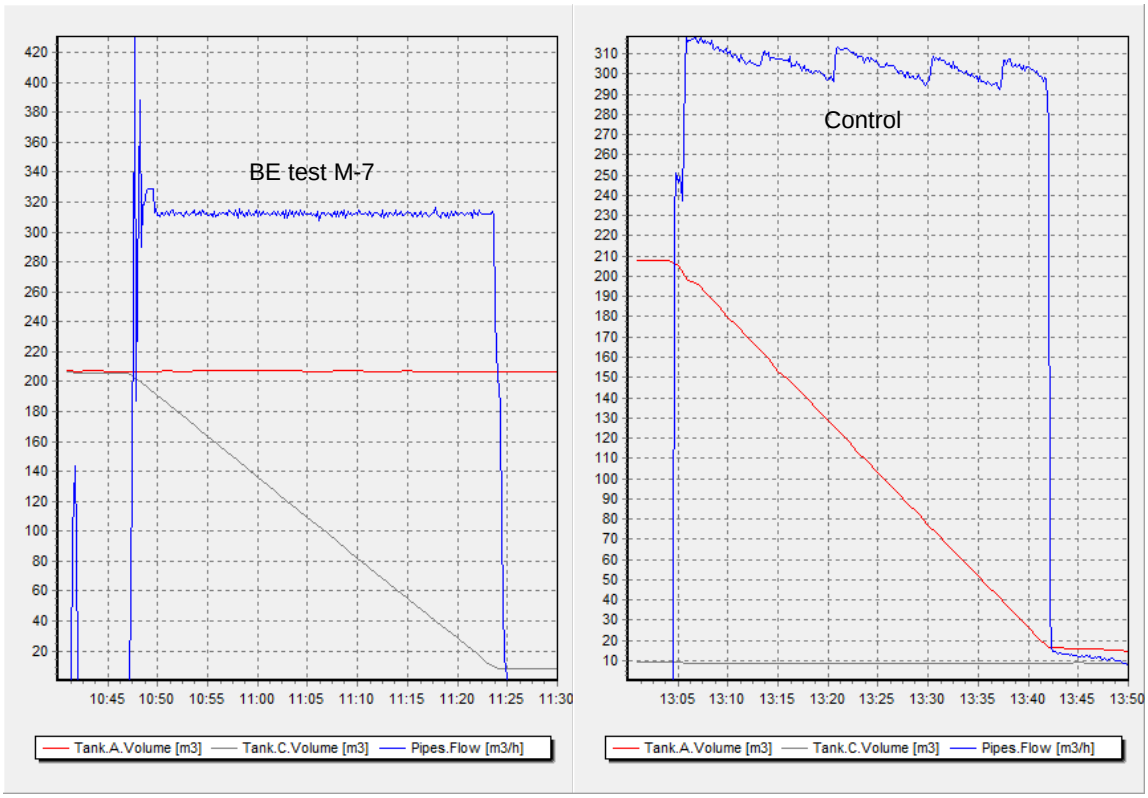

Figure C.17 Biological efficacy test cycle M-7 data plot. De-ballast operation

APPENDIX D

Data logging from the operation and maintenance (O&M) testing with PureBallast 3.0

Table D.1 Operation and maintenance test cycle data logging (O&M-1)

Subject	Results
Client treatment system	PureBallast 3.0
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)	Reactor: 1 AOT (article number 9002698); 10 medium pressure UV lamps Filter: Hydac RF10-25A-11-PFMNB21-H110; 6 mesh candles 50 µm
Test cycle No.	O&M-1
Date and time start	2012.10.12 08:51
Date and time stop	2012.10.12 15:27
System pressure during ballast	2.6 bar
Flow rate during ballast (average)	314 m^3/h
Power consumption	131 kWh
UV intensity	648 W/m^2
Treated volume	2,048 m^3
General comments/operational issues	The O&M test was conducted in ballast mode with filtration and UV treatment. The O&M test was conducted by sea-to-sea operation with ambient water conditions. The flow rate and accumulated volume were measured by a flow meter installed in the piping before the PureBallast BWMS. Detailed online monitoring data available in enclosed data files.

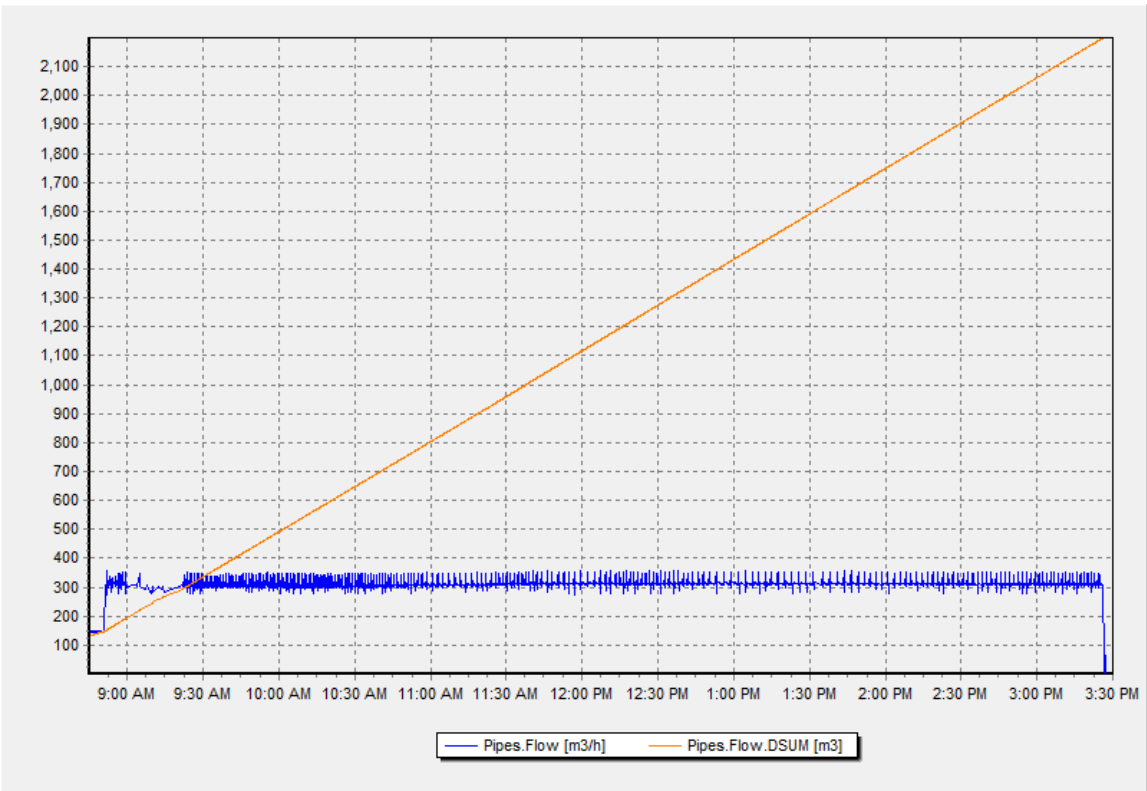

Figure D.1 Operation and maintenance test cycle O&M-1 data plot

Table D.2 Operation and maintenance test cycle data logging (O&M-2)

Subject	Results
Client treatment system	PureBallast 3.0
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)	Reactor: 1 AOT (article number 9002698); 10 medium pressure UV lamps Filter: Hydac RF10-25A-11-PFMNB21-H110; 6 mesh candles 50 µm
Test cycle No.	O&M-2
Date and time start	2012.10.19 06:53
Date and time stop	2012.10.19 13:46
System pressure during ballast	2.9 bar
Flow rate during ballast (average)	297 m^3/h
Power consumption	151 kWh
UV intensity	646 W/m^2
Treated volume	2,031 m^3
General comments/operational issues	The O&M test was conducted in ballast mode with filtration and UV treatment. The O&M test was conducted by sea-to-sea operation with ambient water conditions. The flow rate and accumulated volume were measured by a flow meter installed in the piping before the PureBallast BWMS. Detailed online monitoring data available in enclosed data files.

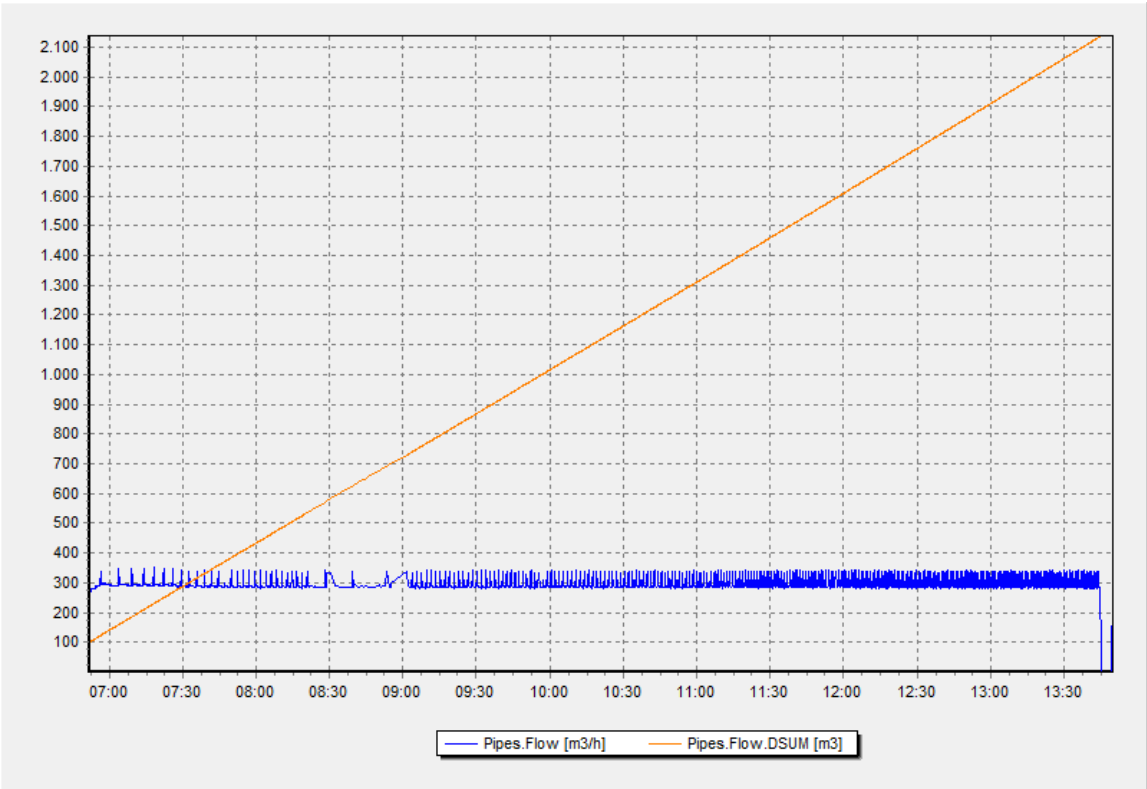

Figure D.2 Operation and maintenance test cycle O&M-2 data plot

Table D.3 Operation and maintenance test cycle data logging (O&M-3)

Subject	Results
Client treatment system	PureBallast 3.0
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)	Reactor: 1 AOT (article number 9002698); 10 medium pressure UV lamps Filter: Hydac RF10-25A-11-PFMNB21-H110; 6 mesh candles 50 µm
Test cycle No.	O&M-3
Date and time start	2012.10.24 09:59
Date and time stop	2012.10.24 16:42
System pressure during ballast	2.6 bar
Flow rate during ballast (average)	316 m^3/h
Power consumption	155 kWh
UV intensity	635 W/m^2
Treated volume	2,110 m^3
General comments/operational issues	The O&M test was conducted in ballast mode with filtration and UV treatment. The O&M test was conducted by sea-to-sea operation with ambient water conditions. The flow rate and accumulated volume were measured by a flow meter installed in the piping before the PureBallast BWMS. Detailed online monitoring data available in enclosed data files.

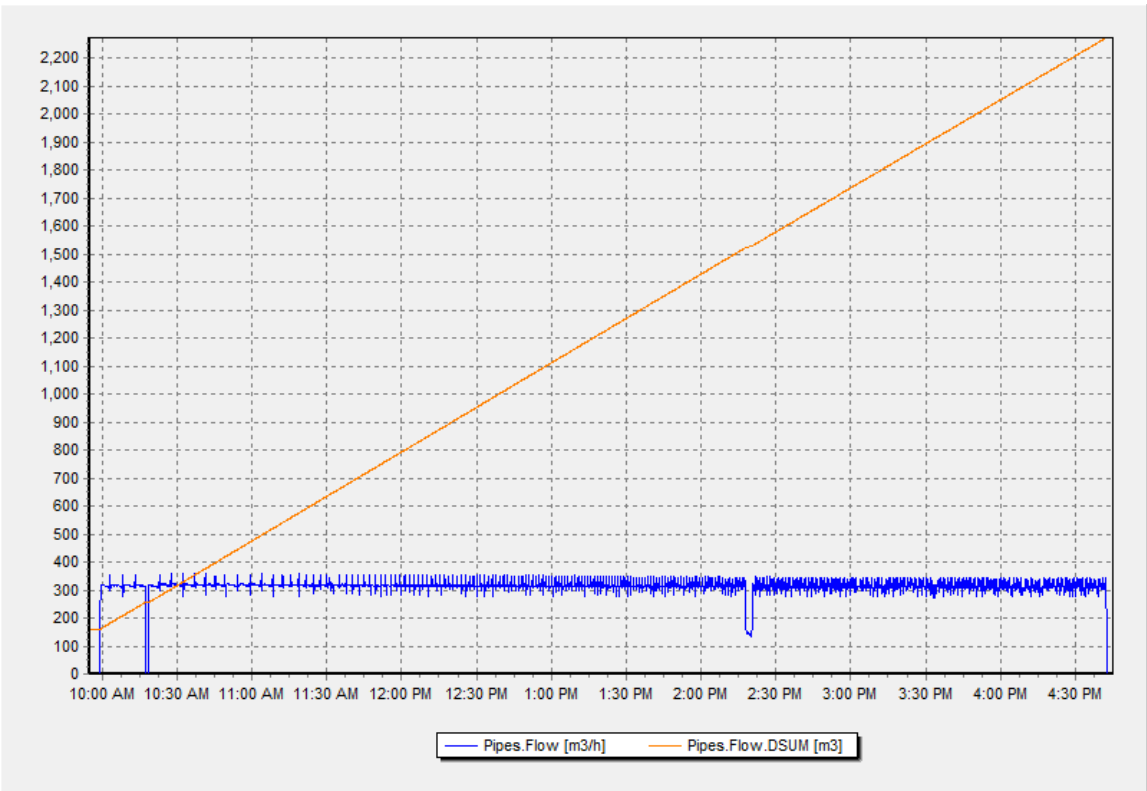

Figure D.3 Operation and maintenance test cycle O&M-3 data plot

Table D.4 Operation and maintenance test cycle data logging (O&M-4)

Subject	Results
Client treatment system	PureBallast 3.0
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)	Reactor: 1 AOT (article number 9002698); 10 medium pressure UV lamps Filter: Hydac RF10-25A-11-PFMNB21-H110; 6 mesh candles 50 µm
Test cycle No.	O&M-4
Date and time start	2012.10.31 07:58
Date and time stop	2012.10.31 15:51
System pressure during ballast	2.7 bar
Flow rate during ballast (average)	318 m^3/h
Power consumption	151 kWh
UV intensity	652 W/m^2
Treated volume	2,046 m^3
General comments/operational issues	The O&M test was conducted in ballast mode with filtration and UV treatment. The O&M test was conducted by sea-to-sea operation with ambient water conditions. The flow rate and accumulated volume were measured by a flow meter installed in the piping before the PureBallast BWMS. The test was paused on three occasions due to power loss (test facility generator failures). PureBallast automatically shut down when power failure occurred. Detailed online monitoring data available in enclosed data files.

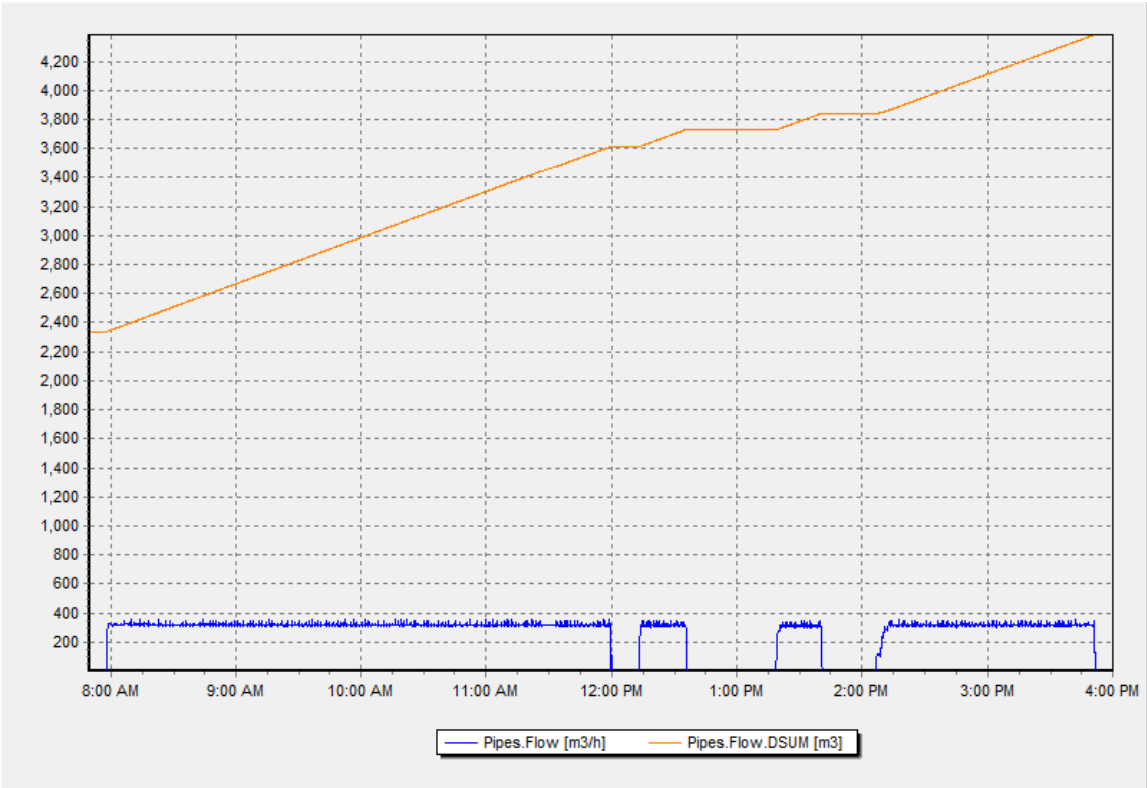

Figure D.4 Operation and maintenance test cycle O&M-4 data plot

Table D.5 Operation and maintenance test cycle data logging (O&M-5)

Subject	Results
Client treatment system	PureBallast 3.0
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)	Reactor: 1 AOT (article number 9002698); 10 medium pressure UV lamps Filter: Hydac RF10-25A-11-PFMNB21-H110; 6 mesh candles 50 µm
Test cycle No.	O&M-5
Date and time start	2012.11.06 11:47
Date and time stop	2012.11.06 18:10
System pressure during ballast	2.8 bar
Flow rate during ballast (average)	318 m^3/h
Power consumption	142 kWh
UV intensity	655 W/m^2
Treated volume	2,036 m^3
General comments/operational issues	The O&M test was conducted in ballast mode with filtration and UV treatment. The O&M test was conducted by sea-to-sea operation with ambient water conditions. The flow rate and accumulated volume were measured by a flow meter installed in the piping before the PureBallast BWMS. Detailed online monitoring data available in enclosed data files.

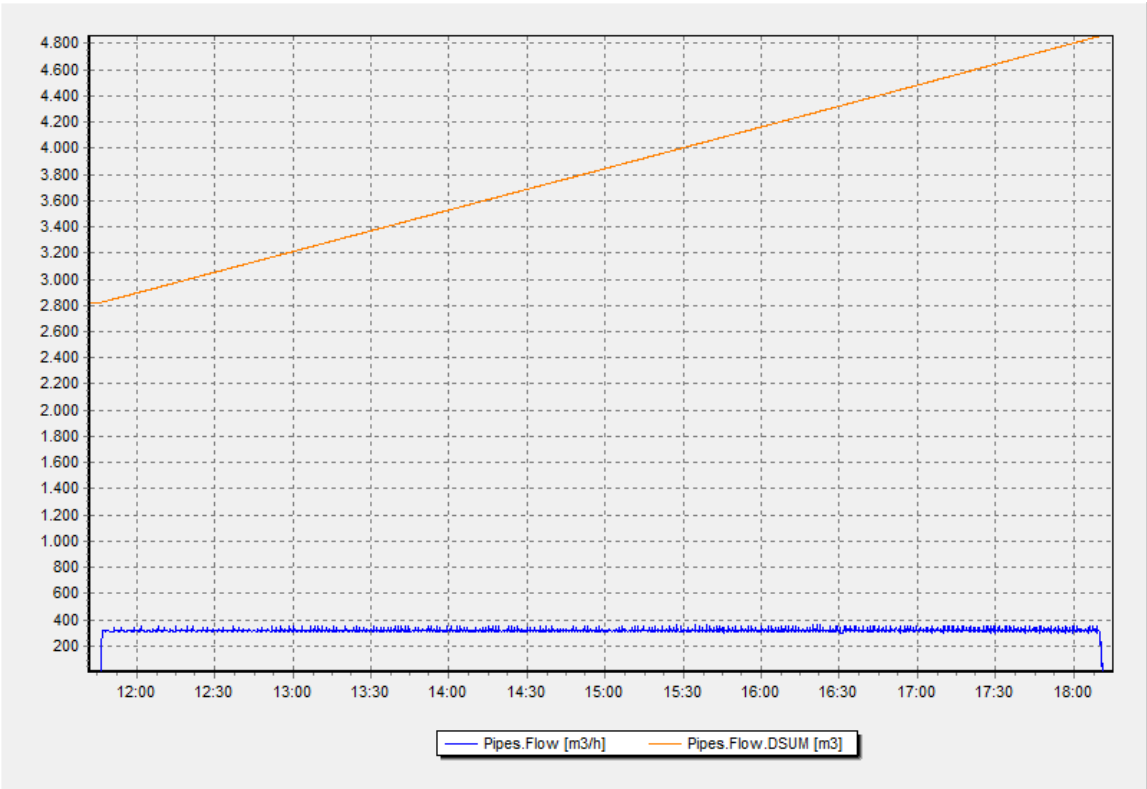

Figure D.5 Operation and maintenance test cycle O&M-5 data plot

APPENDIX E

Detailed data on physical-chemical parameters and biological efficacy analyses in land-based testing with PureBallast 3.0

Physical-chemical parameters

Table E.1 Measurements of total suspended solids (TSS)

Test cycle	Water type	TSS (mg/L)				
		FR1	FR2	FR3	AVG	STD
B-1	Inlet	50	50	48	**49**	±0.79
	Treated T0	50	49	52	**50**	±1.4
	Treated discharge	9.0	9.6	8.4	**9.0**	±0.62
	Control discharge	0.94	0.81	8.1	**3.3**	±4.2
B-2	Inlet	50	50	48	**49**	±0.79
	Treated T0	49	50	52	**50**	±1.6
	Treated discharge	11	11	10	**11**	±0.37
	Control discharge	0.94	0.81	8.1	**3.3**	±4.2
B-3	Inlet	61	67	60	**62**	±3.9
	Treated T0	58	62	60	**60**	±1.9
	Treated discharge	14	13	12	**13**	±1.0
	Control discharge	6.6	5.0	5.7	**5.8**	±0.81
B-4	Inlet	61	67	60	**62**	±3.9
	Treated T0	60	58	58	**59**	±1.1
	Treated discharge	-*	14	13	**13**	±0.43
	Control discharge	6.6	5.0	5.7	**5.8**	±0.81
B-5	Inlet	61	60	60	**60**	±0.25
	Treated T0	57	60	58	**58**	±1.3
	Treated discharge	14	14	13	**14**	±0.43
	Control discharge	2.7	2.8	2.8	**2.8**	±0.03
B-6	Inlet	61	60	60	**60**	±0.25
	Treated T0	60	59	59	**59**	±0.67
	Treated discharge	16	15	13	**15**	±1.7
	Control discharge	2.7	2.8	2.8	**2.8**	±0.03
B-7	Inlet	59	57	58	**58**	±0.80
	Treated T0	55	57	57	**56**	±1.3
	Treated discharge	14	12	12	**13**	±1.0
	Control discharge	8.6	8.0	7.3	**8.0**	±0.65
M-1	Inlet	42	43	41	**42**	±1.1
	Treated T0	37	41	39	**39**	±2.0
	Treated discharge	11	10	9.9	**10**	±0.42
	Control discharge	1.8	2.4	2.7	**2.3**	±0.49
M-2	Inlet	48	47	44	**46**	±2.0
	Treated T0	47	46	46	**46**	±0.18
	Treated discharge	15	13	16	**15**	±1.0
	Control discharge	3.8	3.4	3.0	**3.4**	±0.39
M-3	Inlet	48	47	44	**46**	±2.0
	Treated T0	47	45	58	**50**	±6.9
	Treated discharge	16	16	12	**15**	±2.0
	Control discharge	3.8	3.4	3.0	**3.4**	±0.39
M-4	Inlet	48	48	50	**49**	±1.3
	Treated T0	44	44	44	**44**	±0.19
	Treated discharge	13	12	11	**12**	±0.96
	Control discharge	4.7	4.7	26	**12**	±12

Test cycle	Water type	TSS (mg/L)				
		FR1	FR2	FR3	AVG	STD
M-5	Inlet	48	48	50	**49**	±1.3
	Treated T0	46	49	47	**47**	±1.4
	Treated discharge	14	14	14	**14**	±0.46
	Control discharge	4.7	4.7	26	**12**	±12
M-6	Inlet	48	57	48	**51**	±5.0
	Treated T0	47	50	56	**51**	±4.3
	Treated discharge	17	22	12	**17**	±4.7
	Control discharge	14	5.0	13	**11**	±4.8
M-7	Inlet	61	62	63	**62**	±1.1
	Treated T0	56	59	68	**61**	±6.4
	Treated discharge	9.7	8.2	8.2	**8.7**	±0.86
	Control discharge**	0.46	0.43	0.11	**0.33**	±0.20

* Sample lost
** Values obtained for FR1, FR2 and FR3 were considered incorrect due to equipment error and were classified as “not determined”
FR Field replicate
AVG Average
STD Standard deviation

Table E.2 Measurements of particulate organic carbon (POC)

Test cycle	Water type	POC (mg/L)				
		FR1	FR2	FR3	AVG	STD
B-1	Inlet	6.6	6.7	7.0	**6.7**	±0.19
	Treated discharge	0.56	0.77	1.2	**0.84**	±0.32
	Control discharge	0.57	0.57	0.81	**0.65**	±0.14
B-2	Inlet	6.6	6.7	7.0	**6.7**	±0.19
	Treated discharge	0.79	0.52	0.52	**0.61**	±0.15
	Control discharge	0.57	0.57	0.81	**0.65**	±0.14
B-3	Inlet	6.5	6.9	6.9	**6.8**	±0.24
	Treated discharge	0.71	0.76	0.65	**0.71**	±0.05
	Control discharge	0.66	0.61	0.35	**0.54**	±0.17
B-4	Inlet	6.5	6.9	6.9	**6.8**	±0.24
	Treated discharge	0.93	0.51	0.62	**0.69**	±0.22
	Control discharge	0.66	0.61	0.35	**0.54**	±0.17
B-5	Inlet	7.0	6.7	7.5	**7.1**	±0.40
	Treated discharge	1.6	1.5	1.3	**1.5**	±0.13
	Control discharge	1.4	1.3	1.0	**1.2**	±0.23
B-6	Inlet	7.0	6.7	7.5	**7.1**	±0.40
	Treated discharge	1.4	1.4	1.6	**1.4**	±0.12
	Control discharge	1.4	1.3	1.0	**1.2**	±0.23
B-7	Inlet	7.7	8.3	8.4	**8.1**	±0.37
	Treated discharge	1.0	0.66	0.89	**0.86**	±0.18
	Control discharge	0.90	<0.10	0.63	**0.77**	±0.41
M-1	Inlet	6.4	6.4	6.0	**6.3**	±0.26
	Treated discharge	1.1	1.5	1.3	**1.3**	±0.21
	Control discharge	0.76	0.89	0.33	**0.66**	±0.29
M-2	Inlet	8.2	8.2	7.1	**7.8**	±0.62
	Treated discharge	1.3	1.2	1.3	**1.3**	±0.05
	Control discharge	1.3	0.75	0.81	**1.0**	±0.31
M-3	Inlet	8.2	8.2	7.1	**7.8**	±0.62
	Treated discharge	1.4	1.1	1.0	**1.2**	±0.22
	Control discharge	1.3	0.75	0.81	**1.0**	±0.31
M-4	Inlet	8.4	7.4	8.7	**8.2**	±0.68
	Treated discharge	1.6	0.83	1.2	**1.2**	±0.38
	Control discharge	1.3	0.29	0.42	**0.65**	±0.53
M-5	Inlet	8.4	7.4	8.7	**8.2**	±0.68
	Treated discharge	1.8	1.8	1.6	**1.7**	±0.14
	Control discharge	1.3	0.29	0.42	**0.65**	±0.53
M-6	Inlet	6.9	6.8	9.3	**7.7**	±1.4
	Treated discharge	0.64	2.0	2.1	**1.6**	±0.82
	Control discharge	1.8	0.33	1.4	**1.2**	±0.75
M-7	Inlet	8.4	8.2	7.7	**8.1**	±0.33
	Treated discharge	2.0	2.3	2.5	**2.3**	±0.25
	Control discharge	3.8	3.7	3.8	**3.8**	±0.05

FR Field replicate
AVG Average
STD Standard deviation

Table E.3 Measurements of dissolved organic carbon (DOC)

Test cycle	Water type	DOC (mg/L)				
		FR1	FR2	FR3	AVG	STD
B-1	Inlet	10	10	9.9	**10**	±0.11
	Treated discharge	8.4	8.1	8.1	**8.2**	±0.20
	Control discharge	8.3	8.0	8.0	**8.1**	±0.18
B-2	Inlet	10	10	9.9	**10**	±0.11
	Treated discharge	8.3	8.3	8.4	**8.3**	±0.04
	Control discharge	8.3	8.0	8.0	**8.1**	±0.18
B-3	Inlet	6.0	5.7	5.7	**5.8**	±0.18
	Treated discharge	5.9	5.6	5.7	**5.7**	±0.19
	Control discharge	5.5	5.3	5.5	**5.4**	±0.15
B-4	Inlet	6.0	5.7	5.7	**5.8**	±0.18
	Treated discharge	5.4	5.6	5.8	**5.6**	±0.19
	Control discharge	5.5	5.3	5.5	**5.4**	±0.15
B-5	Inlet	6.5	6.6	6.4	**6.5**	±0.09
	Treated discharge	5.6	5.6	5.8	**5.6**	±0.10
	Control discharge	5.6	5.4	5.6	**5.5**	±0.10
B-6	Inlet	6.5	6.6	6.4	**6.5**	±0.09
	Treated discharge	5.7	5.8	5.5	**5.7**	±0.13
	Control discharge	5.6	5.4	5.6	**5.5**	±0.10
B-7	Inlet	6.7	6.4	6.3	**6.5**	±0.18
	Treated discharge	6.8	6.8	6.5	**6.7**	±0.18
	Control discharge	6.0	6.3	6.3	**6.2**	±0.18
M-1	Inlet	8.1	8.1	8.4	**8.2**	±0.20
	Treated discharge	7.5	7.2	7.0	**7.2**	±0.25
	Control discharge	6.8	6.6	7.1	**6.8**	±0.23
M-2	Inlet	7.2	7.3	7.5	**7.3**	±0.15
	Treated discharge	6.6	6.7	6.6	**6.6**	±0.09
	Control discharge	6.1	6.6	6.6	**6.4**	±0.26
M-3	Inlet	7.2	7.3	7.5	**7.3**	±0.15
	Treated discharge	6.6	6.7	6.6	**6.6**	±0.05
	Control discharge	6.1	6.6	6.6	**6.4**	±0.26
M-4	Inlet	7.4	7.7	6.8	**7.3**	±0.46
	Treated discharge	5.9	4.3	5.7	**5.3**	±0.91
	Control discharge	5.8	5.1	5.2	**5.4**	±0.34
M-5	Inlet	7.4	7.7	6.8	**7.3**	±0.46
	Treated discharge	5.8	5.7	5.9	**5.8**	±0.07
	Control discharge	5.8	5.1	5.2	**5.4**	±0.34
M-6	Inlet	8.1	8.1	7.9	**8.0**	±0.11
	Treated discharge	6.6	6.4	5.1	**6.1**	±0.81
	Control discharge	5.1	6.3	5.8	**5.7**	±0.58
M-7	Inlet	6.1	6.0	5.9	**6.0**	±0.12
	Treated discharge	6.3	5.6	5.9	**5.9**	±0.34
	Control discharge	5.8	5.9	6.0	**5.9**	±0.13

FR Field replicate
AVG Average
STD Standard deviation

Table E.4 Concentration of mineral materials (MM). Concentration determined as the difference between the total suspended solids (TSS) and the particulate organic carbon (POC).

Test cycle	Water type	MM (mg/L)				
		FR1	FR2	FR3	AVG	STD
B-1	Inlet	43	43	41	**42**	±0.98
	Treated discharge	8.5	8.9	7.2	**8.2**	±0.87
	Control discharge	0.37	0.23	7.3	**2.6**	±4.0
B-2	Inlet	43	43	41	**42**	±0.98
	Treated discharge	10	10	10	**10**	±0.23
	Control discharge	0.37	0.23	7.3	**2.6**	±4.0
B-3	Inlet	54	60	53	**56**	±3.8
	Treated discharge	13	12	11	**12**	±0.96
	Control discharge	6.0	4.4	5.4	**5.3**	±0.79
B-4	Inlet	54	60	53	**56**	±3.8
	Treated discharge	-*	13	12	**13**	±0.51
	Control discharge	6.0	4.4	5.4	**5.3**	±0.79
B-5	Inlet	54	54	53	**53**	±0.56
	Treated discharge	12	13	12	**12**	±0.32
	Control discharge	1.3	1.4	1.8	**1.5**	±0.26
B-6	Inlet	54	54	53	**53**	±0.56
	Treated discharge	15	13	11	**13**	±1.8
	Control discharge	1.3	1.4	1.8	**1.5**	±0.26
B-7	Inlet	51	49	50	**50**	±1.1
	Treated discharge	13	11	11	**12**	±0.82
	Control discharge	7.7	8.0	6.7	**7.4**	±0.70
M-1	Inlet	36	37	35	**36**	±0.88
	Treated discharge	10	8.6	8.6	**8.9**	±0.60
	Control discharge	1.0	1.5	2.4	**1.6**	±0.69
M-2	Inlet	40	39	37	**39**	±1.4
	Treated discharge	13	12	14	**13**	±0.98
	Control discharge	2.5	2.7	2.2	**2.5**	±0.22
M-3	Inlet	40	39	37	**39**	±1.4
	Treated discharge	14	15	11	**13**	±1.8
	Control discharge	2.5	2.7	2.2	**2.5**	±0.22
M-4	Inlet	40	40	42	**41**	±0.81
	Treated discharge	11	11	10	**11**	±0.76
	Control discharge	3.4	4.4	26	**11**	±13
M-5	Inlet	40	40	42	**41**	±0.81
	Treated discharge	12	12	13	**12**	±0.57
	Control discharge	3.4	4.4	26	**11**	±13
M-6	Inlet	41	50	39	**43**	±5.9
	Treated discharge	17	20	10	**15**	±4.9
	Control discharge	12	4.7	11	**9.4**	±4.1
M-7	Inlet	53	53	55	**54**	±1.4
	Treated discharge	7.7	6.0	5.7	**7.7**	±1.8
	Control discharge**	n.d.	n.d.	n.d.	-	-

* TSS sample lost
** n.d., not determined (measured value of 0.33 mg TSS/L was considered incorrect; see Table E.1)
FR Field replicate
AVG Average
STD Standard deviation

Table E.5 Measurements of UV transmittance (UV-T)

Test cycle	Water type	UV-T (%)				
		FR1	FR2	FR3	AVG	STD
B-1	Inlet	47	49	48	**48**	±1.0
B-2	Inlet	47	49	48	**48**	±1.0
B-3	Inlet	53	54	52	**53**	±1.0
B-4	Inlet	53	54	52	**53**	±1.0
B-5	Inlet	53	55	52	**53**	±1.5
B-6	Inlet	53	55	52	**53**	±1.5
B-7	Inlet	54	53	55	**54**	±1.1
	Inlet; 0.2-µm filter	77	77	77	**77**	±0.00
M-1	Inlet	54	57	56	**56**	±1.5
M-2	Inlet	56	60	56	**57**	±2.3
M-3	Inlet	56	60	56	**57**	±2.3
M-4	Inlet	57	59	57	**58**	±1.2
M-5	Inlet	57	59	57	**58**	±1.2
M-6	Inlet	55	55	57	**55**	±1.2
	Inlet; 0.2-µm filter	72	73	72	**72**	±0.58
M-7	Inlet	52	52	55	**53**	±1.9
	Inlet; 0.2-µm filter	79	79	79	**79**	±0.44

FR Field replicate
AVG Average
STD Standard deviation

Organism size class ≥50 µm

Table E.6 Enumeration of organisms ≥50 µm. Inlet sample volume: 20 L per field replicate. Treated sample volume: 1,000 L per field replicate.

Test cycle	Water type	Organisms ≥50 µm (organisms/m^3)										
		FR1	FR2	FR3	FR4	FR5	FR6	FR7	FR8	FR9	AVG	STD
B-1	Inlet	262,967	194,317	240,933	277,450	265,717	284,483	220,000	196,333	250,850	**243,672**	±33,468
	Treated T0	9,398	10,738	8,065	-	-	-	-	-	-	**9,400**	±1,336
	Treated discharge*	14	5.0	8.0	-	-	-	-	-	-	**9.0**	±4.6
	Control discharge	59,731	65,205	61,714	-	-	-	-	-	-	**62,217**	±2,771
B-2	Inlet	262,967	194,317	240,933	277,450	265,717	284,483	220,000	196,333	250,850	**243,672**	±33,468
	Treated T0	9,378	12,400	11,554	-	-	-	-	-	-	**11,111**	±1,559
	Treated discharge*	9.0	9.0	13	-	-	-	-	-	-	**10**	±2.3
	Control discharge	59,731	65,205	61,714	-	-	-	-	-	-	**62,217**	±2,771
B-3	Inlet	554,400	631,250	628,800	594,067	533,200	657,600	484,500	666,400	640,617	**598,982**	±62,340
	Treated T0	2,614	2,640	3,540	-	-	-	-	-	-	**2,932**	±527
	Treated discharge*	3.0	2.0	3.0	-	-	-	-	-	-	**2.7**	±0.58
	Control discharge	154,258	147,789	169,149	-	-	-	-	-	-	**157,065**	±10,953
B-4	Inlet	554,400	631,250	628,800	594,067	533,200	657,600	484,500	666,400	640,617	**598,982**	±62,340
	Treated T0	4,120	2,171	1,753	-	-	-	-	-	-	**2,682**	±1,263
	Treated discharge*	1.0	1.0	3.0	-	-	-	-	-	-	**1.7**	±1.2
	Control discharge	154,258	147,789	169,149	-	-	-	-	-	-	**157,065**	±10,953
B-5	Inlet	355,300	355,200	392,200	379,667	364,000	336,400	223,333	301,050	294,533	**333,520**	±52,643
	Treated T0	690	666	438	-	-	-	-	-	-	**598**	±139
	Treated discharge*	0	0	0	-	-	-	-	-	-	**0**	-
	Control discharge	49,490	36,400	40,513	-	-	-	-	-	-	**42,134**	±6,694
B-6	Inlet	355,300	355,200	392,200	379,667	364,000	336,400	223,333	301,050	294,533	**333,520**	±52,643
	Treated T0	1,863	1,910	1,376	-	-	-	-	-	-	**1,716**	±296
	Treated discharge*	1.0	0	1.0	-	-	-	-	-	-	**0.67**	±0.58
	Control discharge	49,490	36,400	40,513	-	-	-	-	-	-	**42,134**	±6,694
B-7	Inlet	290,333	401,667	333,700	337,400	365,500	266,800	-	-	-	**332,567**	±48,975
	Treated T0	4,130	4,904	2,281	-	-	-	-	-	-	**3,772**	±1,348
	Treated discharge*	12	10	3.0	-	-	-	-	-	-	**8.3**	±4.7
	Control discharge	59,431	45,216	51,460	-	-	-	-	-	-	**52,036**	±7,125
M-1	Inlet	161,717	168,350	152,733	198,050	181,500	148,967	-	-	-	**168,553**	±18,538
	Treated T0	1,674	1,810	1,808	-	-	-	-	-	-	**1,764**	±78
	Treated discharge*	0	0	1.0	-	-	-	-	-	-	**0.33**	±0.58
	Control discharge	47,317	45,584	53,820	-	-	-	-	-	-	**48,907**	±4,342
M-2	Inlet	203,933	184,100	219,100	230,350	144,917	199,233	152,000	191,900	157,533	**187,007**	±30,089
	Treated T0	423	529	602	-	-	-	-	-	-	**518**	±90
	Treated discharge*	1.0	0	2.0	-	-	-	-	-	-	**1.0**	±1.0
	Control discharge	14,833	12,250	12,765	-	-	-	-	-	-	**13,283**	±1,367
M-3	Inlet	203,933	184,100	219,100	230,350	144,917	199,233	152,000	191,900	157,533	**187,007**	±30,089
	Treated T0	92	561	484	-	-	-	-	-	-	**379**	±252
	Treated discharge*	1.0	0	0	-	-	-	-	-	-	**0.33**	±0.58

Test cycle	Water type	Organisms ≥50 µm (organisms/m^3)										
		FR1	FR2	FR3	FR4	FR5	FR6	FR7	FR8	FR9	AVG	STD
	Control discharge	14,833	12,250	12,765	-	-	-	-	-	-	**13,283**	±1,367
M-4	Inlet	237,350	262,967	223,636	253,933	228,467	226,800	296,800	222,600	140,850	**232,600**	±19,963
	Treated T0	66	83	0	-	-	-	-	-	-	**50**	±44
	Treated discharge*	0	1.0	0	-	-	-	-	-	-	**0.33**	±0.58
	Control discharge	64,583	55,062	62,626	-	-	-	-	-	-	**60,757**	±5,028
M-5	Inlet	237,350	262,967	223,636	253,933	228,467	226,800	296,800	222,600	140,850	**232,600**	±19,963
	Treated T0	81	0	147	-	-	-	-	-	-	**76**	±74
	Treated discharge*	0	1.0	2.0	-	-	-	-	-	-	**1.0**	±1.0
	Control discharge	64,583	55,062	62,626	-	-	-	-	-	-	**60,757**	±5,028
M-6	Inlet	356,950	236,833	266,933	214,367	218,167	210,400	-	-	-	**250,608**	±56,120
	Treated T0	537	602	517	-	-	-	-	-	-	**552**	±44
	Treated discharge*	11	21	11	-	-	-	-	-	-	**14**	±5.8
	Control discharge	54,188	49,956	48,480	-	-	-	-	-	-	**50,875**	±2,963
M-7	Inlet	337,333	229,917	168,667	197,167	265,417	269,167	-	-	-	**244,611**	±59,779
	Treated T0	786	1,308	932	-	-	-	-	-	-	**1,009**	±269
	Treated discharge*	0	2.0	0	-	-	-	-	-	-	**0.67**	±1.2
	Control discharge	21,875	18,883	18,833	-	-	-	-	-	-	**19,864**	±1,742

FR Field replicate
AVG Average
STD Standard deviation
* The whole treated discharge sample after second treatment was counted

Table E.7 Organisms ≥50 µm identified in inlet and control discharge water

Phylum/ subphylum	Species	Test cycle													
		B-1	B-2	B-3	B-4	B-5	B-6	B-7	M-1	M-2	M-3	M-4	M-5	M-6	M-7
Annelida	*Polychaeta* sp.	X	X			X	X	X	X	X	X			X	
	Polydora sp.	X	X	X	X	X	X		X	X	X	X	X	X	
	Spionida sp.	X	X	X	X	X	X		X			X	X		
	Capitella capitata	X	X	X	X	X	X			X	X				
Bryozoa	*Bryozoa* sp.	X	X	X	X	X	X		X	X	X	X	X		
Cilliophora	*Cilliophora* sp.	X	X									X	X		X
Crustacea	*Acartia clausi*	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Acartia bifilosa											X	X		
	Artemia	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Balanus sp.	X	X	X	X	X	X	X	X	X	X	X	X	X	
	Centropages hamatus							X						X	X
	Evadne nordmanni								X					X	
	Gammarus							X							
	Harpacticoid sp.	X	X	X	X	X	X	X		X	X			X	X
	Isopoda sp.									X	X	X	X		
	Isopoda, Portunion sp.											X	X		
	Mysidacea sp.							X							
	Oithona similis	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Oncaea borealis								X						
	Paracalanus parvus	X	X	X	X	X	X		X	X	X	X	X		
	Podon intermedius			X	X	X	X		X						
	Podon leuckarti														X
	Pseudocalanus minutus			X	X			X	X			X	X	X	X
	Temora longicornis	X	X	X	X	X	X	X	X	X	X	X	X	X	
Dinophyceae	*Ceratium* sp.			X	X	X	X	X	X	X	X	X	X		X
Echinodermata	*Echinodermata* sp.	X	X												
Mollusca	*Bivalve veliger. Mytilus*	X	X	X	X	X	X	X	X	X	X	X	X		X
	Gastropod veliger	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Nematoda	*Nematoda* sp.			X	X										
Platyhelminthes	*Plathyhelminth* sp.														X
Rotifera	*Rotifera. Ascomorpha*							X							
	Rotifera. Keratella	X	X	X	X	X	X		X					X	
	Rotifera. Synchaeta	X	X	X	X	X	X		X	X	X	X	X	X	
	Rotifera. Trichocerca											X	X		
Urochordata	*Larvacea* sp.	X	X						X						

Table E.8 Number of organisms ≥50 µm according to taxonomic group identified in inlet and treated water from test cycles B-1 and B-2

Phylum/ subphylum	Test cycles B-1 and B-2; organisms ≥50 µm (organisms/m^3)																				
	Inlet									Test cycle B-1 Treated T0			Test cycle B-1 Treated discharge			Test cycle B-2 Treated T0			Test cycle B-2 Treated discharge		
	FR1	FR2	FR3	FR4	FR5	FR6	FR7	FR8	FR9	FR1	FR2	FR3	FR1	FR2	FR3	FR1	FR2	FR3	FR1	FR2	FR3
Total number of organisms ≥50 µm	**262,967**	**194,317**	**240,933**	**277,450**	**265,717**	**284,483**	**220,000**	**196,333**	**250,850**	**9,398**	**10,738**	**8,065**	**14**	**5.0**	**8.0**	**9,378**	**12,400**	**11,554**	**9.0**	**9.0**	**13**
Crustacea, artemia	126,117	98,250	115,833	119,333	149,000	126,750	108,533	87,833	141,283	-	-	-	-	-	-	-	-	-	-	-	-
Crustacea, nauplii	37,567	34,933	46,333	53,700	44,700	45,067	32,267	31,000	40,367	6,213	6,552	5,523	5.0	-	1.0	6,686	9,011	8,180	1.0	3.0	2.0
Other crustacea	42,933	21,833	34,750	17,900	24,833	45,067	23,467	25,833	14,417	233	-	-	4.0	5.0	4.0	347	83	169	5.0	5.0	6.0
Annelida	13,417	6,550	2,317	8,950	9,933	11,267	2,933	7,750	2,883	777	1,365	351	5.0	-	3.0	782	496	928	3.0	1.0	5.0
Bryozoa	-	-	-	2,983	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cilliophora	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dinophyceae	5,367	-	-	8,950	7,450	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Echinodermata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mollusca	2,683	4,367	6,950	5,967	-	16,900	8,800	5,167	8,650	-	91	-	-	-	-	-	83	84	-	-	-
Nematoda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Platyhelminthes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rotifera	32,200	26,200	34,750	59,667	27,317	39,433	44,000	38,750	43,250	2,175	2,730	2,192	-	-	-	1,563	2,728	2,193			
Urochordata	2,683	2,183	-	-	2,483	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table E.9 Number of organisms ≥50 µm according to taxonomic group identified in inlet and treated water from test cycles B-3 and B-4

Phylum/ subphylum	Test cycles B-3 and B-4, organisms ≥50 µm (organisms/m^3)																				
	Inlet									Test cycle B-3 Treated T0			Test cycle B-3 Treated discharge			Test cycle B-4 Treated T0			Test cycle B-4 Treated discharge		
	FR1	FR2	FR3	FR4	FR5	FR6	FR7	FR8	FR9	FR1	FR2	FR3	FR1	FR2	FR3	FR1	FR2	FR3	FR1	FR2	FR3
Total number of organisms ≥50 µm	**554,400**	**631,250**	**628,800**	**594,067**	**533,200**	**657,600**	**484,500**	**666,400**	**640,617**	**2,614**	**2,640**	**3,540**	**3.0**	**2.0**	**3.0**	**4,120**	**2,171**	**1,753**	**1.0**	**1.0**	**3.0**
Crustacea, artemia	56,467	55,550	72,000	120,600	107,500	115,200	69,983	108,800	91,517	-	-	-	-	-	-	-	-	-	-	-	-
Crustacea, nauplii	184,800	247,450	235,200	174,200	184,900	254,400	129,200	217,600	231,483	2,024	1,959	2,744	3.0	1.0	1.0	3,507	1,503	1,140	-	-	1.0
Other crustacea	123,200	171,700	163,200	125,067	137,600	148,800	107,667	176,800	145,350	84	85	-	-	1.0	1.0	-	-	-	1.0	1.0	-
Annelida	30,800	5,050	-	31,267	12,900	24,000	48,450	6,800	37,683	-	85	177	-	-	1.0	175	84	88	-	-	-
Bryozoa	-	-	-	-	4,300	4,800	-	-	5,383	-	-	-	-	-	-	-	-	-	-	-	-
Cilliophora	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dinophyceae	5,133	10,100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Echinodermata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mollusca	41,067	35,350	72,000	80,400	25,800	33,600	75,367	68,000	75,367	-	-	89	-	-	-	-	-	-	-	-	-
Nematoda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Platyhelminthes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rotifera	112,933	106,050	86,400	62,533	60,200	76,800	53,833	88,400	53,833	506	511	531	-	-	-	438	585	526	-	-	2.0
Urochordata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table E.10 Number of organisms ≥50 µm according to taxonomic group identified in inlet and treated water from test cycles B-5 and B-6

Phylum/ subphylum	Test cycles B-5 and B-6, organisms ≥50 µm (organisms/m^3)																				
	Inlet									Test cycle B-5 Treated T0			Test cycle B-5 Treated discharge			Test cycle B-6 Treated T0			Test cycle B-6 Treated discharge		
	FR1	FR2	FR3	FR4	FR5	FR6	FR7	FR8	FR9	FR1	FR2	FR3	FR1	FR2	FR3	FR1	FR2	FR3	FR1	FR2	FR3
Total number of organisms ≥50 µm	**355,300**	**355,200**	**392,200**	**379,667**	**364,000**	**336,400**	**223,333**	**301,050**	**294,533**	**690**	**666**	**438**	**0**	**0**	**0**	**1,863**	**1,910**	**1,376**	**1.0**	**0**	**1.0**
Crustacea, artemia	90,567	83,250	79,500	80,400	72,800	69,600	58,067	74,333	68,933	-	-	-	-	-	-	-	-	-	-	-	-
Crustacea, nauplii	90,567	105,450	79,500	80,400	72,800	81,200	75,933	44,600	56,400	197	333	88	-	-	-	1,377	608	602	-	-	-
Other crustacea	20,900	61,050	90,100	49,133	22,750	63,800	49,133	78,050	65,800	-	-	-	-	-	-	-	-	-	1.0	-	1.0
Annelida	-	-	26,500	31,267	31,850	5,800	22,333	18,583	25,067	-	-	-	-	-	-	-	-	-	-	-	-
Bryozoa	-	-	21,200	-	4,550	-	-	-	3,133	-	-	-	-	-	-	-	-	-	-	-	-
Cilliophora	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dinophyceae	20,900	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Echinodermata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mollusca	27,867	38,850	21,200	31,267	40,950	34,800	17,867	26,017	25,067	-	-	-	-	-	-	-	-	-	-	-	-
Nematoda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Platyhelminthes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rotifera	104,500	66,600	74,200	107,200	118,300	81,200	-	59,467	50,133	493	333	351	-	-	-	486	1,303	688	-	-	-
Urochordata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	86	-	-	-

Table E.11 Number of organisms ≥50 µm according to taxonomic group identified in inlet and treated water from test cycle B-7

Phylum/ subphylum	Test cycles B-7, organisms ≥50 µm (organisms/m^3)											
	Inlet						Test cycle B-7 Treated T0			Test cycle B-7 Treated discharge		
	FR1	FR2	FR3	FR4	FR5	FR6	FR1	FR2	FR3	FR1	FR2	FR3
Total number of organisms ≥50 µm	**290,333**	**401,667**	**333,700**	**337,400**	**365,500**	**266,800**	**4,130**	**4,904**	**2,281**	**12**	**10**	**3.0**
Crustacea, artemia	160,800	200,833	152,650	156,650	164,333	100,533	-	-	32	-	-	-
Crustacea, nauplii	67,000	104,433	99,400	108,450	119,000	69,600	3,780	4.6-12	2,089	3.0	1.0	2.0
Other crustacea	35,733	68,283	60,350	52,217	65,167	73,467	35	-	32	-	1.0	-
Annelida	-	4,017	10,650	12,050	11,333	3,867	140	220	64	-	-	-
Bryozoa	-	-	-	-	-	-	-	-	-	-	-	-
Cilliophora	-	-	-	-	-	-	-	-	-	-	-	-
Dinophyceae	-	-	-	-	-	-	-	-	-	-	-	-
Echinodermata	-	-	-	-	-	-	-	-	-	-	-	-
Mollusca	-	-	-	4,017	-	-	-	-	-	-	-	-
Nematoda	4,467	-	-	-	-	-	35	-	-	-	-	-
Platyhelminthes	-	-	-	-	-	-	-	-	-	-	-	-
Rotifera	22,333	20,083	7,100	4,017	5,667	7,733	140	73	64	9.0	8.0	1.0
Urochordata	-	-	-	-	-	-	-	-	-	-	-	-
Sp.	-	4,017	3,550	-	-	11,600	-	-	-	-	-	-

Table E.12 Number of organisms ≥50 µm according to taxonomic group identified in inlet and treated water from test cycle M-1

Phylum/ subphylum	Test cycle M-1, organisms ≥50 µm (organisms/m^3)											
	Inlet						Test cycle M-1 Treated T0			Test cycle M-1 Treated discharge		
	FR1	FR2	FR3	FR4	FR5	FR6	FR1	FR2	FR3	FR1	FR2	FR3
Total number of organisms ≥50 µm	**161,717**	**168,350**	**152,733**	**178,633**	**181,500**	**148,967**	**1,674**	**1,629**	**1,808**	**0**	**0**	**1.0**
Crustacea, artemia	93,900	95,550	92,167	89,317	108,900	72,667	-	-	-	-	-	-
Crustacea, nauplii	-	9,100	10,533	-	3,300	10,900	372	362	1,150	-	-	-
Other crustacea	26,083	45,500	34,233	50,483	42,900	21,800	-	-	-	-	-	-
Annelida	10,433	4,550	2,633	-	3,300	-	-	-	-	-	-	-
Bryozoa	-	-	-	-	-	-	-	-	-	-	-	-
Cilliophora	-	-	-	-	-	-	-	-	-	-	-	-
Dinophyceae	-	-	-	-	-	-	-	-	-	-	-	-
Echinodermata	-	-	-	-	-	-	-	-	-	-	-	-
Mollusca	20,867	13,650	13,167	15,533	19,800	25,433	-	-	-	-	-	-
Nematoda	-	-	-	-	-	-	-	-	-	-	-	-
Platyhelminthes	-	-	-	-	-	-	-	-	-	-	-	-
Rotifera	10,433	-	-	23,300	3,300	18,167	1,302	1,267	657	-	-	1.0
Urochordata	-	-	-	-	-	-	-	-	-	-	-	-
Sp.	-	-	-	-	-	-	-	-	-	-	-	-

Table E.13 Number of organisms ≥50 µm according to taxonomic group identified in inlet and treated water from test cycles M-2 and M-3

Phylum/ subphylum	Test cycles M-2 and M-3; organisms ≥50 µm (organisms/m^3)																				
	Inlet									Test cycle M-2 Treated T0			Test cycle M-2 Treated discharge			Test cycle M-3 Treated T0			Test cycle M-3 Treated discharge		
	FR1	FR2	FR3	FR4	FR5	FR6	FR7	FR8	FR9	FR1	FR2	FR3	FR1	FR2	FR3	FR1	FR2	FR3	FR1	FR2	FR3
Total number of organisms ≥50 µm	**203,933**	**184,100**	**219,100**	**230,350**	**144,917**	**199,233**	**152,000**	**191,900**	**157,533**	**423**	**529**	**602**	**1.0**	**0**	**2.0**	**92**	**561**	**484**	**1.0**	**0**	**0**
Crustacea, artemia	110,833	92,050	135,633	140,017	78,333	125,100	98,800	141,400	101,933	-	-	-	-	-	-	-	-	-	-	-	-
Crustacea, nauplii	31,033	30,683	41,733	36,133	15,667	18,533	7,600	5,050	23,167	169	176	86	-	-	1.0	-	-	97	-	-	-
Other crustacea	26,600	13,150	10,433	22,583	11,750	37,067	22,800	30,300	4,633	85	-	-	-	-	-	-	-	-	1.0	-	-
Annelida	4,433	-	-	-	7,833	-	19,000	-	13,900	-	-	172	-	-	-	92	187	194	-	-	-
Bryozoa	8,867	-	-	4,517	3,917	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cilliophora	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dinophyceae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Echinodermata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mollusca	4,433	17,533	-	9,033	11,750	18,533	3,800	5,050	-	-	-	-	-	-	-	-	-	-	-	-	-
Nematoda	-	-	-	-	-	-	-	-	-	-	88	-	-	-	-	-	-	-	-	-	-
Platyhelminthes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rotifera	17,733	30,683	31,300	18,067	15,667	-	-	10,100	13,900	169	265	344	1.0	-	1.0	-	374	194	-	-	-
Urochordata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table E.14 Number of organisms ≥50 µm according to taxonomic group identified in inlet and treated water from test cycles M-4 and M-5

Phylum/ subphylum	Test cycles M-4 and M-5; organisms ≥50 µm (organisms/m^3)																				
	Inlet									Test cycle M-4 Treated T0			Test cycle M-4 Treated discharge			Test cycle M-5 Treated T0			Test cycle M-5 Treated discharge		
	FR1	FR2	FR3	FR4	FR5	FR6	FR7	FR8	FR9	FR1	FR2	FR3	FR1	FR2	FR3	FR1	FR2	FR3	FR1	FR2	FR3
Total number of organisms ≥50 µm	**237,350**	**262,967**	**223,636**	**253,933**	**228,467**	**226,800**	**296,800**	**222,600**	**140,850**	**66**	**83**	**0**	**0**	**1.0**	**0**	**81**	**0**	**147**	**0**	**1.0**	**2.0**
Crustacea, artemia	106,050	120,050	119,273	117,200	104,300	105,300	143,100	63,600	83,467	-	-	-	-	-	-	-	-	-	-	-	-
Crustacea, nauplii	35,350	51,450	19,879	39,067	24,833	24,300	26,500	26,500	-	-	83	-	-	-	-	-	-	-	-	-	-
Other crustacea	60,600	68,600	64,606	78,133	79,467	81,000	79,500	68,900	36,517	-	-	-	-	-	-	-	-	-	-	-	1.0
Annelida	-	-	-	-	4,967	-	5,300	5,300	-	-	-	-	-	-	-	-	-	-	-	-	-
Bryozoa	5,050	-	-	4,883	-	-	10,600	-	5,217	-	-	-	-	-	-	-	-	-	-	-	-
Cilliophora	-	-	-	-	-	-	5,300	-	-	-	-	-	-	-	-	-	-	-	-	1.0	-
Dinophyceae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Echinodermata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mollusca	5,050	11,433	14,909	-	4,967	4,050	-	26,500	-	-	-	-	-	-	-	-	-	-	-	-	-
Nematoda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Platyhelminthes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rotifera	25,250	11,433	4,970	14,650	9,933	12,150	26,500	31,800	15,650	66	-	-	-	1.0	-	81	-	147	-	-	1.0
Urochordata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table E.15 Number of organisms ≥50 µm according to taxonomic group identified in inlet and treated water from test cycle M-6

Phylum/ subphylum	Test cycle M-6, organisms ≥50 µm (organisms/m^3)											
	Inlet						Test cycle M-6 Treated T0			Test cycle M-6 Treated discharge		
	FR1	FR2	FR3	FR4	FR5	FR6	FR1	FR2	FR3	FR1	FR2	FR3
Total number of organisms ≥50 µm	**356,950**	**236,833**	**266,933**	**214,367**	**218,167**	**210,400**	**537**	**602**	**517**	**11**	**21**	**11**
Crustacea, artemia	72,600	57,517	62,400	54,500	51,567	17,533	289	172	470	-	-	-
Crustacea, nauplii	145,200	67,667	76,267	65,400	59,500	74,517	83	129	-	7	18	10
Other crustacea	102,850	91,350	100,533	79,933	75,367	78,900	-	86	-	1.0	-	-
Annelida	12,100	13,533	6,933	14,533	19,833	13,150	124	215	47	-	-	-
Bryozoa	-	-	-	-	-	-	-	-	-	-	-	-
Cilliophora	-	-	-	-	-	-	-	-	-	-	-	-
Dinophyceae	-	-	-	-	-	-	-	-	-	-	-	-
Echinodermata	-	-	-	-	-	-	-	-	-	-	-	-
Mollusca	-	-	-	-	3,967	-	-	-	-	-	-	-
Nematoda	-	-	-	-	-	-	-	-	-	-	-	-
Platyhelminthes	-	-	-	-	-	-	-	-	-	-	-	-
Rotifera	24,200	6,767	20,800	-	7,933	26,300	41	-	-	3.0	3.0	-
Urochordata	-	-	-	-	-	-	-	-	-	-	-	-
Sp.	-	-	-	-	-	-	-	-	-	-	-	1.0

Table E.16 Number of organisms ≥50 µm according to taxonomic group identified in inlet and treated water from test cycle M-7

Phylum/ subphylum	Test cycle M-7, organisms ≥50 µm (organisms/m^3)											
	Inlet						Test cycle M-7 Treated T0			Test cycle M-7 Treated discharge		
	FR1	FR2	FR3	FR4	FR5	FR6	FR1	FR2	FR3	FR1	FR2	FR3
Total number of organisms ≥50 µm	**337,333**	**229,917**	**168,667**	**197,167**	**265,417**	**269,167**	**786**	**1,308**	**932**	**0**	**2.0**	**0**
Crustacea, artemia	95,333	81,583	69,000	68,250	68,250	95,000	604	945	599	-	-	-
Crustacea, nauplii	29,333	-	7,667	-	-	-	-	73	-	-	-	-
Other crustacea	51,333	14,833	7,667	22,750	7,583	47,500	-	-	133	-	1.0	-
Annelida	-	-	-	-	-	-	-	73	-	-	-	-
Bryozoa	-	-	-	-	-	-	-	-	-	-	-	-
Cilliophora	-	-	-	-	-	-	-	-	-	-	-	-
Dinophyceae	7,333	-	-	-	37,917	23,750	-	-	-	-	-	-
Echinodermata	-	-	-	-	-	-	-	-	-	-	-	-
Mollusca	154,000	133,500	84,333	106,167	151,667	102,917	181	145	200	-	1.0	-
Nematoda	-	-	-	-	-	-	-	73	-	-	-	-
Platyhelminthes	-	-	-	-	-	-	-	-	-	-	-	-
Rotifera	-	-	-	-	-	-	-	-	-	-	-	-
Urochordata	-	-	-	-	-	-	-	-	-	-	-	-
Sp.	-	-	-	-	-	-	-	-	-	-	-	-

Organism size class ≥10 and <50 µm

Table E.17 Enumeration of organisms ≥10 µm and <50 µm by microscopy after staining with CMFDA and FDA. The motile organisms without chlorophyll are included in the total number of organisms.

Test cycle	Water type	Organisms ≥10 µm and <50 µm (organisms/mL)									
		Total number of organisms					Motile organisms without chlorophyll				
		FR1	FR2	FR3	AVG	STD	FR1	FR2	FR3	AVG	STD
B-1	Inlet	1,653	1,144	1,206	**1,334**	±278	-	-	-	**-**	-
	Treated discharge	14	23	20	**19**	±4.6	0	0	0.10	**0.03**	±0.06
	Control discharge	546	590	580	**572**	±23	-	-	-	**-**	-
B-2	Inlet	1,653	1,144	1,206	**1,334**	±278	-	-	-	**-**	-
	Treated discharge	28	30	25	**28**	±2.5	0	0	0	**0**	-
	Control discharge	546	590	580	**572**	±23	-	-	-	**-**	-
B-3	Inlet	3,444	2,739	2,726	**2,970**	±411	-	-	-	**-**	-
	Treated discharge	17	14	8.5	**13**	±4.2	0	0	0	**0**	-
	Control discharge	457	457	480	**464**	±13	-	-	-	**-**	-
B-4	Inlet	3,444	2,739	2,726	**2,970**	±411	-	-	-	**-**	-
	Treated discharge	16	20	14	**17**	±2.8	0	0	0	**0**	-
	Control discharge	457	457	480	**464**	±13	-	-	-	**-**	-
B-5	Inlet	2,267	1,851	2,578	**2,232**	±365	-	-	-	**-**	-
	Treated discharge	12	14	6.6	**11**	±4.0	0.10	0.10	0	**0.07**	±0.06
	Control discharge	327	313	533	**391**	±123	-	-	-	**-**	-
B-6	Inlet	2,267	1,851	2,578	**2,232**	±365	-	-	-	**-**	-
	Treated discharge	8.6	10	10	**9.8**	±1.0	0	0	0	**0**	-
	Control discharge	327	313	533	**391**	±123	-	-	-	**-**	-
B-7	Inlet	2,895	3,947	3,917	**3,586**	±599	-	-	-	**-**	-
	Treated discharge	72	40	36	**49**	±20	0	0	0	**0**	-
	Control discharge	1,015	1,200	1,440	**1,218**	±213	58	100	85	**81**	±21
M-1	Inlet	1,585	1,886	1,675	**1,715**	±154	-	-	-	**-**	-
	Treated discharge	43	42	40	**42**	±1.9	1.4	0	0	**0.48**	±0.82
	Control discharge	3,687	3,750	4,630	**4,022**	±527	-	-	-	**-**	-
M-2	Inlet	1,651	1,345	1,526	**1,508**	±154	-	-	-	**-**	-
	Treated discharge	69	59	68	**65**	±5.5	0	0	0	**0**	-
	Control discharge	445	568	515	**509**	±61	-	-	-	**-**	-
M-3	Inlet	1,651	1,345	1,526	**1,508**	±154	-	-	-	**-**	-
	Treated discharge	69	66	43	**59**	±14	0	0	0	**0**	-
	Control discharge	445	568	515	**509**	±61	-	-	-	**-**	-
M-4	Inlet	1,458	1,156	1,050	**1,221**	±212	-	-	-	**-**	-
	Treated discharge	51	52	50	**51**	±0.95	0	0	0	**0**	-
	Control discharge	590	620	590	**600**	±17	-	-	-	**-**	-
M-5	Inlet	1,458	1,156	1,050	**1,221**	±212	-	-	-	**-**	-
	Treated discharge	42	35	30	**36**	±5.8	0	0	0	**0**	-
	Control discharge	590	620	590	**600**	±17	-	-	-	**-**	-

Test cycle	Water type	Organisms ≥10 µm and <50 µm (organisms/mL)									
		Total number of organisms					Motile organisms without chlorophyll				
		FR1	FR2	FR3	AVG	STD	FR1	FR2	FR3	AVG	STD
M-6	Inlet	8,064	8,278	7,778	**8,040**	±251	-	-	-	-	-
	Treated discharge	329	289	231	**283**	±49	0	0	0	**0**	±0
	Control discharge	1,250	1,270	1,200	**1,240**	±36	60	40	20	**40**	±20
M-7	Inlet	2,342	2,264	2,264	**2,290**	±45	-	-	-	**-**	-
	Treated discharge	24	27	30	**27**	±3.0	0	0	0	**0**	-
	Treated discharge (combined sample, stored and analysed 1 d after discharge)*	19			-	-	2.0			-	-
	Treated discharge (combined sample, stored and analysed 2 d after discharge)*	10			-	-	2.0			-	-
	Treated discharge (combined sample, stored and analysed 3 d after discharge)*	7.0			-	-	0			-	-
	Treated discharge (combined sample, stored and analysed 8 d after discharge)*	2.0			-	-	0			-	-
	Control discharge	260	235	275	**257**	±20	55	38	85	**59**	±24
	Control discharge (combined sample, stored and analysed 1 d after discharge)*	268			-	-	52			-	-
	Control discharge (combined sample, stored and analysed 2 d after discharge)*	356			-	-	72			-	-
	Treated discharge (combined sample, stored and analysed 3 d after discharge)*	344			-	-	68			-	-
	Treated discharge (combined sample, stored and analysed 8 d after discharge)*	305			-	-	135			-	-

* Samples collected as part of supplemental study described in Appendix G
FR Field replicate
AVG Average
STD Standard deviation

Table E.18 Most probable number of proliferating algae (algal re-growth assay)

Test cycle	Water type	Viable algae (organisms/mL)				
		FR1	FR2	FR3	AVG	STD
B-1	Inlet	>16,000	>16,000	>16,000	**>16,000**	-
	Treated discharge	0.45 (0.11-1.8)	0.18 (0.02-1.4)	<0.18	**0.27**	-
	Control discharge	1,600 (540-4,800)	>1,600	1,600 (540-4,800)	**>1,600**	-
B-2	Inlet	>16,000	>16,000	>16,000	**>16,000**	-
	Treated discharge	0.40 (0.1-1.7)	1.1 (0.38-3.0)	0.20 (0.03-1.4)	**0.57**	±0.47
	Control discharge	1,600 (540-4,800)	>1,600	1,600 (540-4,800)	**>1,600**	-
B-3	Inlet	16,000 (5,400-48,000)	>16,000	>16,000	**>16,000**	-
	Treated discharge	<0.18	0.18 (0.02-1.4)	0.18 (0.02-1.4)	**0.18**	-
	Control discharge	>1,600	>1,600	>1,600	**>1,600**	-
B-4	Inlet	16,000 (5,400-48,000)	>16,000	>16,000	**>16,000**	-
	Treated discharge	<0.18	<0.18	<0.18	**<0.18**	-
	Control discharge	>1,600	>1,600	>1,600	**>1,600**	-
B-5	Inlet	16,000 (5,400-48,000)	16,000 (5,400-48,000)	>16,000	**16,000**	-
	Treated discharge	<0.18	<0.18	<0.18	**<0.18**	-
	Control discharge	>1,600	>1,600	920 (290-2,900)	**1,373**	-
B-6	Inlet	16,000 (5,400-48,000)	16,000 (5,400-48,000)	>16,000	**16,000**	-
	Treated discharge	<0.18	<0.18	<0.18	**<0.18**	-
	Control discharge	>1,600	>1,600	920 (290-2,900)	**1,373**	-
B-7	Inlet	9,200 (2,900-29,000)	5,400 (1,600-18,000)	5,400 (1,600-18,000)	**6,667**	±2,194
	Treated discharge	2.3 (0.88-6.1)	3.3 (1.2-9.2)	3.3 (1.2-9.2)	**3.0**	±0.58
	Control discharge	>1,600	>1,600	>1,600	**>1,600**	-
M-1	Inlet	9,200 (2,900-29,000)	>16,000	>16,000	**13,733**	-
	Treated discharge	<0.18	<0.18	<0.18	**<0.18**	-
	Control discharge	920 (290-2,900)	920 (290-2,900)	>1,600	**1,147**	-
M-2	Inlet	2,400 (890-6,400)	3,500 (1,200-10,000)	3,500 (1,200-10,000)	**3,133**	±635
	Treated discharge	0.18 (0.02-1.4)	<0.18	<0.18	**<0.18**	-
	Control discharge	350 (120-1,000)	>1,600	540 (160-1,800)	**830**	-
M-3	Inlet	2,400 (890-6,400)	3,500 (1,200-10,000)	3,500 (1,200-10,000)	**3,133**	±635
	Treated discharge	<0.18	<0.18	<0.18	**<0.18**	-
	Control discharge	350 (120-1,000)	>1,600	540 (160-1,800)	**830**	-

Test cycle	Water type	Viable algae (organisms/mL)				
		FR1	FR2	FR3	AVG	STD
M-4	Inlet	3,500 (1,200-10,000)	2,400 (890-6,400)	3,500 (1,200-10,000)	**3,133**	±635
	Treated discharge	<0.18	<0.18	<0.18	**<0.18**	-
	Control discharge	1,600 (540-4,800)	1,600 (540-4,800)	920 (290-2,900)	**1,373**	±393
M-5	Inlet	3,500 (1,200-10,000)	2,400 (890-6,400)	3,500 (1,200-10,000)	**3,133**	±635
	Treated discharge	<0.18	<0.18	<0.18	**<0.18**	-
	Control discharge	1,600 (540-4,800)	1,600 (540-4,800)	920 (290-2,900)	**1,373**	±393
M-6	Inlet	3,500 (1,200-10,000)	1,700 (650-4,600)	16,000 (5,400-48,000)	**7,067**	±7,789
	Treated discharge	160 (54-480)	35 (12-100)	54 (16-180)	**83**	±67
	Control discharge	540 (160-1,800)	540 (160-1,800)	350 (120-1,000)	**477**	±110
M-7	Inlet	5,400 (1,600 - 18,000)	>16,000	9,200 (2,900 - 29,000)	**10,200**	±5,370
	Treated discharge	<0.18	<0.18	<0.18	**<0.18**	-
	Control discharge	170 (65 - 460)	240 (89 - 640)	540 (160 - 1,800)	**317**	±197

FR Field replicate
AVG Average
STD Standard deviation
( ) 95% confidence interval

Table E.19 Measurements of algal primary production

Test cycle	Water type	Primary production (DPM)				
		FR1	FR2	FR3	AVG	STD
B-1	Inlet	4,570	4,948	5,263	**4,927**	±347
	Treated T0	897	869	876	**881**	±14
	Treated discharge	0	0	0	**0**	-
	Control discharge	280	230	250	**253**	±25
B-2	Inlet	4,570	4,948	5,263	**4,927**	±347
	Treated T0	941	911	668	**840**	±150
	Treated discharge	0	0	0	**0**	-
	Control discharge	280	230	250	**253**	±25
B-3	Inlet	8,292	9,011	7,943	**8,415**	±545
	Treated T0	418	435	400	**418**	±18
	Treated discharge	3.6	0	0	**1.2**	±2.1
	Control discharge	311	817	918	**682**	±325
B-4	Inlet	8,292	9,011	7,943	**8,415**	±545
	Treated T0	384	389	426	**400**	±23
	Treated discharge	0	0	0	**0**	-
	Control discharge	311	817	918	**682**	±325
B-5	Inlet	7,254	7,504	7,055	**7,271**	±225
	Treated T0	310	316	270	**299**	±25
	Treated discharge	0	0	0	**0**	-
	Control discharge	486	564	649	**567**	±82
B-6	Inlet	7,254	7,504	7,055	**7,271**	±225
	Treated T0	302	348	319	**323**	±23
	Treated discharge	0	0	0	**0**	-
	Control discharge	486	564	649	**567**	±82
B-7	Inlet	8,223	7,054	7,808	**7,695**	±593
	Treated T0	656	663	663	**661**	±3.7
	Treated discharge	6.0	1.7	0.54	**2.8**	±2.9
	Control discharge	1,285	1,287	957	**1,177**	±190
M-1	Inlet	5,189	6,996	6,290	**6,158**	±910
	Treated T0	584	597	815	**665**	±130
	Treated discharge	1.4	2.1	1.9	**1.8**	±0.36
	Control discharge	554	693	1,359	**869**	±431
M-2	Inlet	3,102	3,327	3,360	**3,263**	±115
	Treated T0	549	568	524	**547**	±22
	Treated discharge	4.3	1.1	2.6	**2.7**	±1.3
	Control discharge	1,204	1,347	1,617	**1,389**	±171
M-3	Inlet	3,102	3,327	3,360	**3,263**	±115
	Treated T0	544	544	523	**537**	±9.8
	Treated discharge	2.6	0.24	0	**0.93**	±1.2
	Control discharge	1,204	1,347	1,617	**1,389**	±171

Test cycle	Water type	Primary production (DPM)				
		FR1	FR2	FR3	AVG	STD
M-4	Inlet	1,788	2,312	2,169	**2,090**	±270
	Treated T0	392	374	367	**378**	±13
	Treated discharge	0	0	0	**0**	-
	Control discharge	677	738	1,324	**913**	±357
M-5	Inlet	1,788	2,312	2,169	**2,090**	±270
	Treated T0	360	343	370	**357**	±14
	Treated discharge	4.8	5.3	0.54	**3.5**	±2.6
	Control discharge	677	738	1,324	**913**	±357
M-6	Inlet	2,322	3,192	3,458	**2,990**	±594
	Treated T0	724	677	662	**688**	±33
	Treated discharge	28	24	19	**24**	±4.5
	Control discharge	383	379	539	**434**	±91
M-7	Inlet	4,586	4,690	4,868	**4,714**	±142
	Treated T0	530	655	620	**602**	±65
	Treated discharge	4.7	1.8	1.2	**2.6**	±1.9
	Control discharge	126	55	238	**140**	±93

DPM Disintegrations per minute
FR Field replicate
AVG Average
STD Standard deviation

Table E.20 Algal taxa and species identified in inlet water and their capability of growth under the conditions applied in the algal re-growth assay

Phylum/ subphylum	Species	B-1	B-2	B-3	B-4	B-5	B-6	B-7	M-1	M-2	M-3	M-4	M-5	M-6	M-7	Capable of growing in re-growth assay
Bacillario-phyceae	*Cerataulina pelagica*					X	X			X	X					X
	Chaetoceros affinis														X	X
	Chaetoceros compressus							X							X	X
	Chaetoceros curvisetus	X	X	X	X	X	X		X	X	X			X		X
	Chaetoceros danicus							X								X
	Chaetoceros debilis			X	X	X	X			X	X			X		X
	Chaetoceros gracilis							X								
	Coscinodiscus granii											X	X			X
	Coscinodiscus radiata					X	X		X	X	X	X	X			X
	Cyclotella bodanica													X		
	Dactyliosolen fragilissimus	X	X	X	X	X	X		X	X	X	X	X			X
	Ditylum brightwellii			X	X				X	X	X	X	X			X
	Guinardia delicatula			X	X				X							X
	Guinardia flaccida					X	X									X
	Lauderia annulata									X	X					X
	Leptocylindrus danicus							X		X	X			X		X
	Leptocylindrus minimus									X	X					X
	Licmophora sp.			X	X			X	X	X	X			X	X	X
	Melosira nummuloides														X	X
	Navicula crabo			X	X											
	Nitzschia longissima/ Cylindrotheca closterium														X	X
	Porosira glacialis									X	X					X
	Proboscia alata									X	X					X
	Rhizosolenia styliformis								X							
	Skeletonema costatum							X	X			X	X	X	X	X
	Stephanopyxis turris													X		X
	Thalassionema nitzschioides									X	X	X	X		X	X
	Thalassiosira baltica							X								X
	Thalassiosira nordenskioldii											X	X			X
	Thalassiosira sp.											X	X			X
Chlorophyceae	*Tetraselmis* sp.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Cryptophyceae	cf. *Cryptomonas* sp.	X	X													X
Dictyocophyceae	*Dictyocha speculum*					X	X			X	X					
Dinophyceae	*Amphidinium* sp.	X	X					X								X
	Ceratium furca			X	X					X	X				X	X
	Ceratium fusus			X	X	X	X		X	X	X	X	X		X	
	Dinophysis acuminata											X	X			X
	Dinophysis sp.	X	X	X	X	X	X									X
	Gyrodinium glaucum					X	X									
	Heterocapsa triquetra								X							X
	Katodinium glaucum	X	X	X	X				X	X	X	X	X	X		X
	Prorocentrum sp.	X	X													
	Prorocentrum micans					X	X		X	X	X	X	X		X	X
	Protoperidinium depressum			X	X	X	X			X	X	X	X			

Organism size class <10 µm (bacteria)

Table E.21 Enumeration of heterotrophic bacteria

Test cycle	Water type	Heterotrophic bacteria (CFU/mL)				
		FR1	FR2	FR3	AVG	STD
B-1	Inlet	183,000	162,500	160,000	**168,500**	±12,619
	Treated T0	61	50	44	**52**	±8.6
	Control discharge	166,000	166,000	132,500	**154,833**	±19,341
B-2	Inlet	183,000	162,500	160,000	**168,500**	±12,619
	Treated T0	53	26	30	**36**	±15
	Control discharge	166,000	166,000	132,500	**154,833**	±19,341
B-3	Inlet	99,100	94,500	103,000	**98,867**	±4,255
	Treated T0	69	101	127	**99**	±29
	Control discharge	>200,000	>200,000	>200,000	**>200,000**	-
B-4	Inlet	99,100	94,500	103,000	**98,867**	±4,255
	Treated T0	185	69	49	**101**	±73
	Control discharge	>200,000	>200,000	>200,000	**>200,000**	-
B-5	Inlet	52,950	47,300	56,800	**52,350**	±4,778
	Treated T0	51	51	39	**47**	±6.8
	Control discharge	>200,000	>200,000	>200,000	**>200,000**	-
B-6	Inlet	52,950	47,300	56,800	**52,350**	±4,778
	Treated T0	38	26	26	**30**	±6.9
	Control discharge	>200,000	>200,000	>200,000	**>200,000**	-
B-7	Inlet	90,900	77,250	83,200	**83,783**	±6,844
	Treated T0	33	23	14	**23**	±10
	Control discharge	105,250	101,500	115,500	**107,417**	±7,247
M-1	Inlet	116,000	98,200	132,000	**115,400**	±16,908
	Treated T0	64	62	53	**60**	±5.8
	Control discharge	>200,000	>200,000	>200,000	**>200,000**	-
M-2	Inlet	512,500	485,000	330,000	**442,500**	±80,338
	Treated T0	101	113	93	**102**	±8.2
	Control discharge	143,500	145,000	132,000	**140,167**	±5,807
M-3	Inlet	512,500	485,000	330,000	**442,500**	±80,338
	Treated T0	49	33	52	**45**	±8.3
	Control discharge	143,500	145,000	132,000	**140,167**	±5,807
M-4	Inlet	285,000	285,000	250,000	**273,333**	±20,207
	Treated T0	118	235	220	**191**	±64
	Control discharge	>200,000	>200,000	>200,000	**>200,000**	-
M-5	Inlet	285,000	285,000	250,000	**273,333**	±20,207
	Treated T0	67	41	97	**68**	±28
	Control discharge	>200,000	>200,000	>200,000	**>200,000**	-
M-6	Inlet	59,750	64,500	60,000	**61,417**	±2,673
	Treated T0	65	61	33	**53**	±17
	Treated discharge	1.0	5.0	6.0	**4.0**	±2.6
	Control discharge	171,750	>200,000	167,500	**179,750**	±17,665
M-7	Inlet	572,500	795,000	570,000	**645,833**	±129,188
	Treated T0	568	225	310	**368**	±178
	Treated discharge	259	56	50	**122**	±119
	Control discharge	177,000	184,000	183,000	**181,333**	±3,786

CFU Colony-forming units
FR Field replicate
AVG Average
STD Standard deviation

Table E.22 Enumeration of enterococci

Test cycle	Water type	Enterococci (CFU/100 mL)				
		FR1	FR2	FR3	AVG	STD
B-1	Inlet	260	134	103	**166**	±83
	Treated discharge	<1	<1	<1	**<1**	-
	Control discharge	1.5	<1	<1	**1.2**	-
B-2	Inlet	260	134	103	**166**	±83
	Treated discharge	<1	<1	<1	**<1**	-
	Control discharge	1.5	<1	<1	**1.2**	-
B-3	Inlet	426	168	135	**243**	±159
	Treated discharge	<1	<1	<1	**<1**	-
	Control discharge	131	106	68	**102**	±32
B-4	Inlet	426	168	135	**243**	±159
	Treated discharge	<1	<1	<1	**<1**	-
	Control discharge	131	106	68	**102**	±32
B-5	Inlet	649	579	752	**660**	±87
	Treated discharge	<1	<1	<1	**<1**	-
	Control discharge	113	94	50	**86**	±32
B-6	Inlet	649	579	752	**660**	±87
	Treated discharge	2.0	<1	<1	**1.3**	-
	Control discharge	113	94	50	**86**	±32
B-7	Inlet	20	<10	41	**24**	±16
	Treated discharge	<1	<1	<1	**<1**	-
	Control discharge	11	9.0	12	**11**	±1.5
M-1	Inlet	770	411	397	**526**	±212
	Treated discharge	<1	1.0	<1	**<1**	-
	Control discharge	179	163	150	**164**	±15
M-2	Inlet	770	345	488	**534**	±216
	Treated discharge	<1	<1	<1	**<1**	-
	Control discharge	16	15	23	**18**	±4.4
M-3	Inlet	770	345	488	**534**	±216
	Treated discharge	<1	<1	<1	**<1**	-
	Control discharge	16	15	23	**18**	±4.4
M-4	Inlet	>2,420	>2,420	>2,420	**>2,420**	-
	Treated discharge	<1	<1	<1	**<1**	-
	Control discharge	2,077	980	687	**1,248**	±732
M-5	Inlet	>2,420	>2,420	>2,420	**>2,420**	-
	Treated discharge	<1	<1	<1	**<1**	-
	Control discharge	2,077	980	687	**1,248**	±732
M-6	Inlet	>2,420	>2,420	>2,420	**>2,420**	-
	Treated discharge	1.0	<1.0	1.0	**<1.0**	-
	Control discharge	326	293	365	**328**	±36
M-7	Inlet	>2,420	2,420	>2,420	**>2,420**	-
	Treated discharge	32	6.5	7.0	**15**	±15
	Control discharge	25	19	15	**20**	±5.0

CFU Colony-forming units
FR Field replicate
AVG Average
STD Standard deviation

Table E.23 Enumeration of *E. coli*

Test cycle	Water type	*E. coli (CFU/100 mL)*				
		FR1	FR2	FR3	AVG	STD
B-1	Inlet	<10	<10	<10	<10	-
	Treated discharge	<10	<10	<10	**<10**	-
	Control discharge	>24,200	>24,200	>24,200	**>24,200**	-
B-2	Inlet	<10	<10	<10	**<10**	-
	Treated discharge	<10	<10	<10	**<10**	-
	Control discharge	>24,200	>24,200	>24,200	**>24,200**	-
B-3	Inlet	<10	<10	<10	**<10**	-
	Treated discharge	<10	<10	<10	**<10**	-
	Control discharge	<10	<10	<10	**<10**	-
B-4	Inlet	<10	<10	<10	**<10**	-
	Treated discharge	<10	<10	<10	**<10**	-
	Control discharge	<10	<10	<10	**<10**	-
B-5	Inlet	<10	<10	<10	**<10**	-
	Treated discharge	<10	<10	<10	**<10**	-
	Control discharge	<10	<10	<10	**<10**	-
B-6	Inlet	<10	<10	<10	**<10**	-
	Treated discharge	<10	<10	<10	**<10**	-
	Control discharge	<10	<10	<10	**<10**	-
B-7	Inlet	660	754	689	**701**	±48
	Treated discharge	<10	<10	<10	**<10**	-
	Control discharge	2,360	2,760	3,435	**2,852**	±543
M-1	Inlet	<10	<10	<10	**<10**	-
	Treated discharge	<10	<10	<10	**<10**	-
	Control discharge	30	10	<10	**17**	-
M-2	Inlet	<10	<10	10	**<10**	-
	Treated discharge	<10	<10	<10	**<10**	-
	Control discharge	10	<10	<10	**<10**	-
M-3	Inlet	<10	<10	10	**<10**	-
	Treated discharge	<10	<10	<10	**<10**	-
	Control discharge	10	<10	<10	**<10**	-
M-4	Inlet	<10	<10	<10	**<10**	-
	Treated discharge	<10	<10	<10	**<10**	-
	Control discharge	<10	10	<10	**<10**	-
M-5	Inlet	<10	<10	<10	**<10**	-
	Treated discharge	<10	10	<10	**<10**	-
	Control discharge	<10	10	<10	**<10**	-
M-6	Inlet	<10	<10	<10	**<10**	-
	Treated discharge	<10	<10	<10	**<10**	-
	Control discharge	<10	<10	<10	**<10**	-
M-7	Inlet	<10	<10	<10	**<10**	-
	Treated discharge	<10	<10	<10	**<10**	-
	Control discharge	<10	<10	<10	**<10**	-

CFU Colony-forming units
FR Field replicate
AVG Average
STD Standard deviation

Table E.24 Enumeration of *Vibrio cholerae*

Test cycle	Water type	*Vibrio cholerae* (CFU/100 mL)				
		FR1	FR2	FR3	AVG	STD
B-1	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
B-2	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
B-3	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
B-4	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
B-5	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
B-6	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
B-7	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
M-1	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
M-2	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
M-3	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
M-4	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
M-5	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
M-6	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
M-7	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-

CFU Colony-forming units
FR Field replicate
AVG Average
STD Standard deviation

APPENDIX F

Data logging and detailed data on physical-chemical parameters and biological efficacy analyses from test cycle conducted with PureBallast 3.0 and older version Boll & Kirch filter 6.18.2

Table F.1 Biological test cycle data logging

Subject	Results
Client treatment system	PureBallast 3.0
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)	Reactor: 1 AOT (article number 9002698); 10 medium pressure UV lamps Filter: Boll & Kirch (type 6.18.2 BWT DN 200); 20 mesh candles 40 µm
Salinity	19 PSU
Retention tank No.	B1
Test cycle	PureBallast 3.0 with Boll & Kirch 6.18.2
Use of cultured/harvested organisms	Addition backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae
System cleaned before ballast	Yes
Date and time ballast start	2012.11.22 09:16
Date and time ballast stop	2012.11.22 09:57
System pressure during ballast	3.0 bar
Flow rate during ballast	345 m^3/h
Flow rate to ballast tank	310 m^3/h
Power consumption during ballast	23 kWh
UV intensity	459 W/m^2
Treated volume during ballast	209 m^3 + 3 m^3 sampled
Volume used for ballasting	236 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2012.11.27 09:20
Date and time de-ballast stop	2012.11.27 09:57
System pressure during de-ballast	1.2 bar
Flow rate during de-ballast	323 m^3/h
Power consumption during de-ballast	19 kWh
UV intensity	506 W/m^2
Treated volume during de-ballast	199 m^3
General comments/operational issues	Detailed online monitoring data available in enclosed data files

Table F.2 Onsite measurements (standard deviations in parentheses)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Control inlet	100 (±0.22)	8.1 (±0.00)	19 (±0.04)	6.6 (±0.01)	30 (±0.50)
PureBallast inlet	100 (±0.24)	8.1 (±0.00)	19 (±0.00)	6.7 (±0.01)	30 (±0.55)
PureBallast treated T0	100 (±0.39)	8.0 (±0.01)	19 (±0.01)	6.8 (±0.01)	32 (±0.68)
PureBallast before treatment T5	87 (±1.3)	7.9 (±0.02)	19 (±0.00)	6.7 (±0.03)	9.1 (±0.50)
PureBallast treated discharge	86 (±0.46)	7.8 (±0.02)	19 (±0.00)	6.7 (±0.02)	9.3 (±0.30)
Control discharge	82 (±0.90)	7.9 (±0.01)	19 (±0.02)	6.6 (±0.07)	5.7 (±1.8)

PSU Practical salinity units
NTU Nephelometric turbidity units

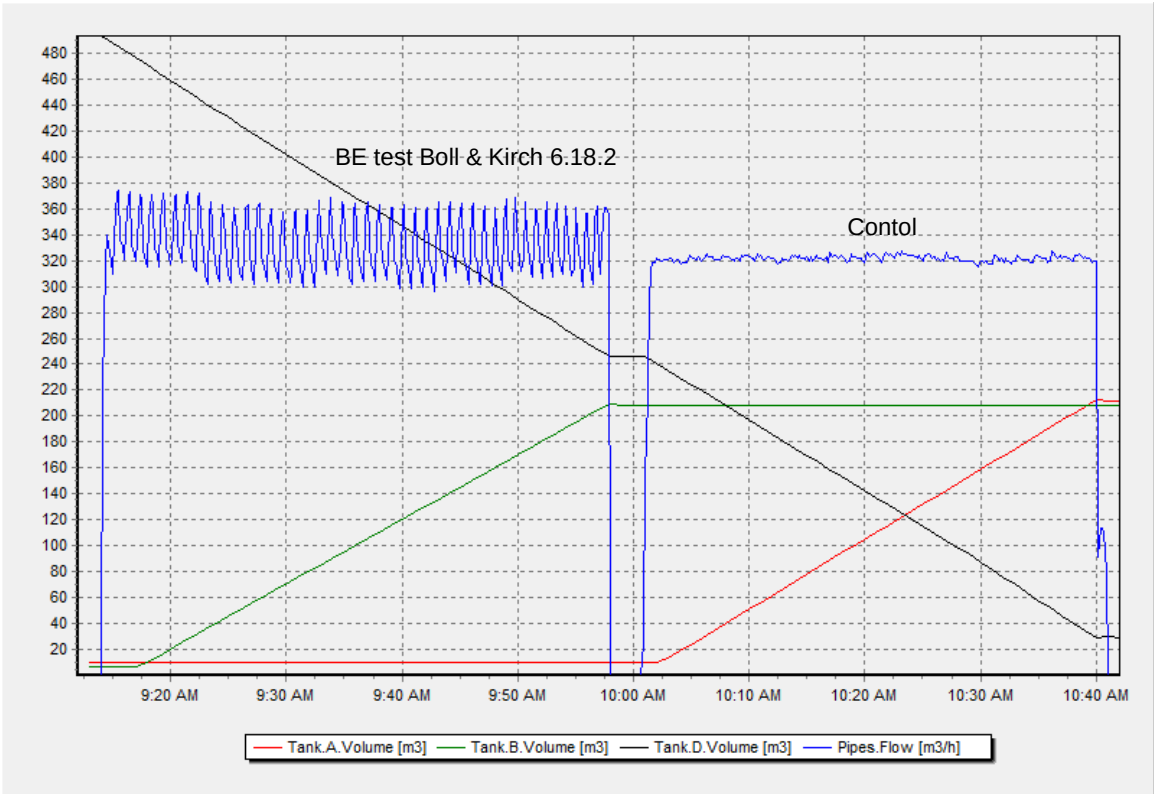

Figure F.1 Biological efficacy test cycle with Boll & Kirch 6.18.2. Ballast operation

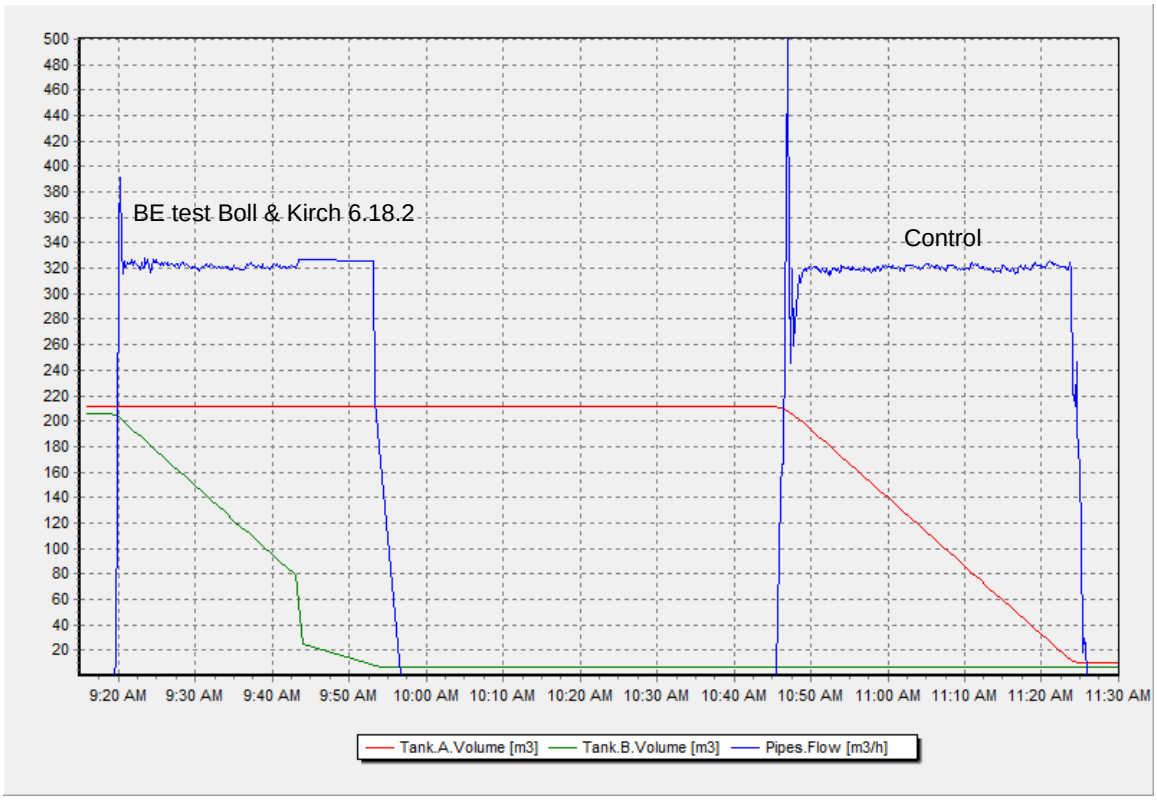

Figure F.2 Biological efficacy test cycle with Boll & Kirch 6.18.2. De-ballast operation

Physical-chemical parameters

Table F.3 Measurements of total suspended solids (TSS)

Date and test setup	Water type	TSS (mg/L)				
		FR1	FR2	FR3	AVG	STD
2012.11.22-27: PureBallast 3.0 - Boll & Kirch 6.18.2	Inlet	60	61	61	**61**	±0.57
	Treated T0	59	61	58	**59**	±1.1
	Treated discharge	12	12	11	**12**	±0.46
	Control discharge	9.0	6.9	5.9	**7.3**	±1.6

FR Field replicate
AVG Average
STD Standard deviation

Table F.4 Measurements of particulate organic carbon (POC)

Date and test setup	Water type	POC (mg/L)				
		FR1	FR2	FR3	AVG	STD
2012.11.22-27: PureBallast 3.0 - Boll & Kirch 6.18.2	Inlet	-	-	-	**5.5***	-
	Treated discharge	1.1	1.1	1.1	**1.1**	±0.02
	Control discharge	1.4	1.2	1.6	**1.4**	±0.20

* Nominal concentrations of POC and DOC in the inlet water were applied as the TOC analyser was not operating correctly at the time of sampling. Subsequent analyses of preserved samples were attempted but the analyses provided non-reliable results.
FR Field replicate
AVG Average
STD Standard deviation

Table F.5 Measurements of dissolved organic carbon (DOC)

Date and test setup	Water type	DOC (mg/L)				
		FR1	FR2	FR3	AVG	STD
2012.11.22-27: PureBallast 3.0 - Boll & Kirch 6.18.2	Inlet	-	-	-	**6.6***	-
	Treated discharge	6.2	6.0	6.0	**6.0**	±0.09
	Control discharge	5.8	5.8	5.6	**5.8**	±0.10

* Nominal concentrations of POC and DOC in the inlet water were applied as the TOC analyser was not operating correctly at the time of sampling. Subsequent analyses of preserved samples were attempted but the analyses provided non-reliable results.
FR Field replicate
AVG Average
STD Standard deviation

Table F.6 Concentration of mineral materials (MM). Concentration determined as the difference between the total suspended solids (TSS) and the particulate organic carbon (POC).

Date and test setup	Water type	MM (mg/L)				
		FR1	FR2	FR3	AVG	STD
2012.11.22-27: PureBallast 3.0 - Boll & Kirch 6.18.2	Inlet	58	56	53	**56**	±2.9
	Treated discharge	11	11	10	**11**	±0.47
	Control discharge	7.5	5.8	4.3	**5.9**	±1.6

FR Field replicate
AVG Average
STD Standard deviation

Table F.7 Measurements of UV transmittance (UV-T)

Date and test setup	Water type	UV-T (%)				
		FR1	FR2	FR3	AVG	STD
2012.11.22-27: PureBallast 3.0 - Boll & Kirch 6.18.2	Inlet	52	52	54	**53**	±1.2

FR Field replicate
AVG Average
STD Standard deviation

Organism size class ≥50 µm

Table F.8 Enumeration of organisms ≥50 µm. Inlet sample volume: 20 L per field replicate. Treated sample volume: 1,000 L per field replicate.

Date and test setup	Water type	Organisms ≥50 µm (organisms/m^3)							
		FR1	FR2	FR3	FR4	FR5	FR6	AVG	STD
2012.11.22-27: PureBallast 3.0 - Boll & Kirch 6.18.2	Inlet	415,350	376,350	362,017	343,175	359,883	463,667	**386,740**	±44,888
	Treated T0	14,105	17,971	16,027	-	-	-	**16,034**	±1,933
	Treated discharge	258	266	274	-	-	-	**266**	±8.1
	Control discharge	68,790	74,278	72,538	-	-	-	**71,869**	±2,804

FR Field replicate
AVG Average
STD Standard deviation

Table F.9 Organisms ≥50 µm identified in inlet and control discharge water

Phylum/ subphylum	Species	2012.11.22-27: PureBallast 3.0 - Boll & Kirch 6.18.2
Annelida	*Polychaeta* sp.	X
	Capitella capitata	X
Bryozoa	*Bryozoa* sp.	X
Cilliophora	*Cilliophora* sp.	X
Crustacea	*Acartia clausi*	X
	Artemia	X
	Balanus sp.	X
	Evadne nordmanni	X
	Harpacticoid sp.	X
	Isopoda, Portunion sp.	X
	Oithona similis	X
	Ostracoda sp.	X
	Paracalanus parvus	X
	Podon leuckarti	X
	Temora longicornis	X
Dinophyceae	*Ceratium* sp.	X
Mollusca	*Bivalve veliger. Mytilus*	X
	Gastropod veliger	X
Rotifera	*Rotifera. Synchaeta*	X

Table F.10 Number of organisms ≥50 µm according to taxonomic group identified in inlet and treated water

Phylum/ subphylum	2012.11.22-27: PureBallast 3.0 - Boll & Kirch 6.18.2 Organisms ≥50 µm (organisms/m^3)											
	Inlet						Treated T0			Treated discharge		
	FR1	FR2	FR3	FR4	FR5	FR6	FR1	FR2	FR3	FR1	FR2	FR3
Total number of organisms ≥50 µm	**415,350**	**376,350**	**362,017**	**343,175**	**359,883**	**463,667**	**14,105**	**17,971**	**16,027**	**258**	**266**	**274**
Crustacea, artemia	53,250	64,333	43,983	50,730	52,433	60,667	91	-	-	-	-	-
Crustacea, nauplii	152,650	128,667	104,883	98,476	100,100	156,000	9,919	12,697	10,818	58	40	48
Other Crustacea	71,000	54,683	64,283	95,492	76,267	78,000	182	391	200	3.0	-	-
Annelida	3,550	3,217	3,383	-	-	-	-	-	100	-	-	-
Bryozoa	-	-	-	2,984	2,383	-	-	98	-	-	-	-
Cilliophora	-	-	-	-	-	-	-	-	-	-	-	-
Dinophyceae	71,000	61,117	84,583	53,714	73,883	91,000	-	-	-	-	-	-
Echinodermata	-	-	-	-	-	-	-	-	-	-	-	-
Mollusca	-	3,217	3,383	-	2,383	-	-	98	-	-	-	-
Nematoda	-	-	-	-	-	-	-	-	-	-	-	-
Platyhelminthes	-	-	-	-	-	-	-	-	-	-	-	-
Rotifera	63,900	61,117	57,517	38,794	52,433	78,000	3,913	4,688	4,908	197	225	226
Urochordata	-	-	-	-	-	-	-	-	-	-	-	-
Sp.	-	-	-	2,984	-	-	-	-	-	-	-	-

Organism size class ≥10 and <50 µm

Table F.11 Enumeration of organisms ≥10 µm and <50 µm by microscopy after staining with CMFDA and FDA. The motile organisms without chlorophyll are included in the total number of organisms.

Date and test setup	Water type	Organisms ≥10 µm and <50 µm (organisms/mL)									
		Total number of organisms					Motile organisms without chlorophyll				
		FR1	FR2	FR3	AVG	STD	FR1	FR2	FR3	AVG	STD
2012.11.22-27: PureBallast 3.0 - Boll & Kirch 6.18.2	Inlet	1,400	1,401	1,304	**1,368**	±56	-	-	-	-	-
	Treated discharge	36	50	45	**44**	±6.7	0	0	0	0	-
	Treated discharge (combined sample, stored and analysed 1 d after discharge)*	15			-	-	0			-	-
	Treated discharge (combined sample, stored and analysed 2 d after discharge)*	8.7			-	-	0			-	-
	Treated discharge (combined sample, stored and analysed 3 d after discharge)*	6.5			-	-	0			-	-
	Control discharge	633	473	528	**544**	±81	20	2.5	3.3	**8.6**	±9.9
	Control discharge (combined sample, stored and analysed 1 d after discharge)*	688			-	-	0			-	-
	Control discharge (combined sample, stored and analysed 2 d after discharge)*	833			-	-	0			-	-
	Treated discharge (combined sample, stored and analysed 3 d after discharge)*	800			-	-	0			-	-

* Samples collected as part of supplemental study described in Appendix G
FR Field replicate
AVG Average
STD Standard deviation

Table F.12 Most probable number of proliferating algae (algal re-growth assay)

Date and test setup	Water type	Viable algae (organisms/mL)				
		FR1	FR2	FR3	AVG	STD
2012.11.22-27: PureBallast 3.0 - Boll & Kirch 6.18.2	Inlet	16,000 (5,400-48,000)	9,200 (2,900-29,000)	5,400 (1,600-18,000)	**10,200**	±5,370
	Treated discharge	<0.18	<0.18	0.20 (0.03-1.4)	**0.20**	-
	Control discharge	>1,600	>1,600	>1,600	**>1,600**	-

FR Field replicate
AVG Average
STD Standard deviation
( ) 95% confidence interval

Table F.13 Measurements of algal primary production

Date and test setup	Water type	Primary production (DPM)				
		FR1	FR2	FR3	AVG	STD
2012.11.22-27 - PureBallast 3.0 - Boll & Kirch 6.18.2	Inlet	6,584	6,798	6,814	**6,732**	±128
	Treated T0	1,349	1,438	1,447	**1,411**	±54
	Treated discharge	2.1	0.86	0.43	**1.1**	±0.89
	Control discharge	1,541	1,863	3,311	**2,238**	±943

DPM Disintegrations per minute
FR Field replicate
AVG Average
STD Standard deviation

Table F.14 Algal taxa and species identified in inlet water and their capability of growth under the conditions applied in the algal re-growth assay

Phylum/ subphylum	Species	2012.11.22-27: PureBallast 3.0 – Boll & Kirch 6.18.2	Capable of growing in re-growth assay
Bacillariophyceae	*Dactyliosolen fragilissimus*	X	X
	Ditylum brightwellii	X	X
	Licmophora sp.	X	X
	Rhizosolenia delicatula	X	
	Rhizosolenia styliformis	X	
	Thalassionema nitzschioides	X	X
Chlorophyceae	*Tetraselmis* sp.	X	X
Dictyocophyceae	*Dictyocha speculum*	X	
Dinophyceae	*Ceratium furca*	X	X
	Ceratium fusus	X	
	Heterocapsa sp	X	X
	Prorocentrum micans	X	X

Organism size class <10 µm (bacteria)

Table F.15 Enumeration of heterotrophic bacteria

Date and test setup	Water type	Heterotrophic bacteria (CFU/mL)				
		FR1	FR2	FR3	AVG	STD
2012.11.22-27: PureBallast 3.0 - Boll & Kirch 6.18.2	Inlet	60,900	60,900	60,900	**60,900**	-
	Treated T0	65	50	485	**200**	±247
	Control discharge	247,500	290,000	335,000	**290,833**	±43,756

CFU Colony-forming units
FR Field replicate
AVG Average
STD Standard deviation

Table F.16 Enumeration of enterococci

Date and test setup	Water type	Enterococci (CFU/100 mL)				
		FR1	FR2	FR3	AVG	STD
2012.11.22-27_: PureBallast 3.0 - Boll & Kirch 6.18.2	Inlet	548	488	116	**384**	±234
	Treated discharge	<1	<1	<1	**<1**	-
	Control discharge	8.1	10	6.0	**8.0**	±2.0

CFU Colony-forming units
FR Field replicate
AVG Average
STD Standard deviation

Table F.17 Enumeration of *E. coli*

Date and test setup	Water type	*E. coli* (CFU/100 mL)				
		FR1	FR2	FR3	AVG	STD
2012.11.22-27: PureBallast 3.0 - Boll & Kirch 6.18.2	Inlet	10	20	30	**20**	±10
	Treated discharge	<10	<10	<10	**<10**	-
	Control discharge	<10	<10	<10	**<10**	-

CFU Colony-forming units
FR Field replicate
AVG Average
STD Standard deviation

Table F.18 Enumeration of *Vibrio cholerae*

Date and test setup	Water type	*Vibrio cholerae* (CFU/100 mL)				
		FR1	FR2	FR3	AVG	STD
2012.11.22-27: PureBallast 3.0 - Boll & Kirch 6.18.2	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-

CFU Colony-forming units
FR Field replicate
AVG Average
STD Standard deviation

APPENDIX G

Supplemental study on ‘die-away’ of CMFDA/FDA-stained fluorescent cells in test water treated by PureBallast 3.0

Supplemental study on 'die-away' of CMFDA/FDA-stained fluorescent cells in test water treated by PureBallast 3.0

A supplemental study was conducted with treated test water to examine the time-dependent 'die-away' of fluorescent cells after staining with CMFDA and FDA. The hypothesis was that UV-exposed algae in the ≥10 and <50 µm size class are actually dying after UV exposure although they fluoresce after staining with CMFDA and FDA when analysed in the epifluorescence microscope at discharge after five days of storage in the retention tank.

The supplemental study was conducted in relation to two of the test cycles with PureBallast 3.0 to examine whether UV-exposed algae ≥10 and <50 µm can be considered to be dying at the point of discharge, which would be supported if a marked decrease in the number of fluorescent cells was observed after incubation beyond the 5-day storage time. The two test cycles providing samples for the supplemental study were the brackish water test cycle with the Boll & Kirch filter 6.18.2 (described in Appendix F) and the marine water test cycle M-7.

Following microscopy counting after staining with CMFDA and FDA within 6 hours after discharge, the three treated field replicates were blended into one sample, and the three control discharge field replicates were blended into one sample. These two blended samples were stored at approx. 5°C in darkness. The blended samples were re-analysed by microscopic counting after staining with CMFDA and FDA after 24, 48 and 72 hours. The blended sample from test cycle M-7 was also re-analysed after 192 hours. The results of this experiment are illustrated in Figure G.1.

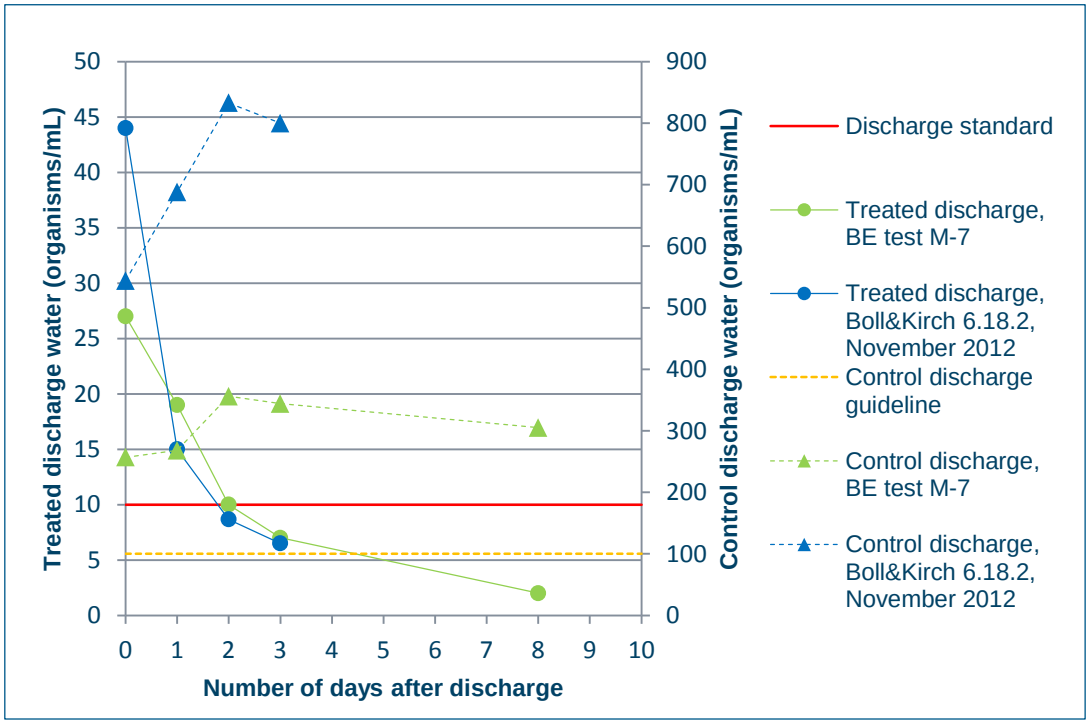

Figure G.1 Time-dependent effects of PureBallast 3.0 treatment. Comparison of fluorescent organisms ≥10 and <50 µm after staining with CMFDA and FDA in treated discharge and non-treated control discharge water.

The numbers of fluorescent organisms were stable or even increased with time in the control discharge water whereas, in the treated discharge water, the fluorescent organisms decreased markedly with time. It is seen that the numbers of fluorescent organisms in the treated discharge water were close to the ballast water discharge standard after 48 hours and below the discharge standard after 72 hours.

APPENDIX H

Quality control and quality assurance for performance evaluation in land-based test facility with PureBallast 3.0

Quality control and quality assurance	Description	Overall responsible
Quality control, data from laboratory analyses and database entries	All results related to samples and laboratory analyses are stored in relevant databases. All data entries in databases have been quality controlled. Laboratory records are filed in the DHI archives.	Last data entry 7 August 2013 Camilla Hedberg
Quality control, onsite data from the DHI Maritime Technology Evaluation Facility, Hundested	Logging of data related to the activities at the test facility was conducted for each individual test cycle. Operational data and extracts from the DHI online monitoring system were quality controlled as part of the reporting process. Onsite data records are filed in the DHI archives.	Quality control last data set 16 August 2013 Camilla Hedberg
Quality control, interim test cycle reports	All data related to a specific test cycle have been reported in interim test cycle reports. Reports have been written by members of the project team upon completion of quality control of all data sets. Each interim test cycle report has been quality controlled.	Quality control last interim report 21 August 2013 Torben Madsen
Quality control, draft final report	Data and data interpretation related to the present performance evaluation have been quality controlled, and all data are truly and accurately presented in the final report.	Quality control final report 2 September 2013 Torben Madsen
Quality assurance (draft final report)	The performance evaluation in land-based test facility for PureBallast 3.0 complies with the conditions outlined in the QMP, QAPP and SOPs. The performance evaluation was conducted in compliance with the IMO G8 guidelines and ETV protocol. The guidance requirements for biological efficacy test cycles were consistently fulfilled except for minor deviations, which were considered negligible and were appropriately addressed in the final report	Quality assurance of project 12 September 2013 Louise Schlüter
Quality control, final report	Data and data interpretation related to the present performance evaluation have been quality controlled, and all data are truly and accurately presented in the final report.	Quality control final report 16 December 2013 Torben Madsen
Quality assurance (final report)	The performance evaluation in land-based test facility for PureBallast 3.0 complies with the conditions outlined in the QMP, QAPP and SOPs. The performance evaluation was conducted in compliance with the IMO G8 guidelines and ETV protocol. The guidance requirements for biological efficacy test cycles were consistently fulfilled except for minor deviations, which were considered negligible and were appropriately addressed in the final report	Quality assurance of project 17 December 2013 Louise Schlüter

APPENDIX I

Certificate of compliance, ISO 9001 certificate, accreditation and GLP authorisation

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Certificate no: **DS/I093222-A**
Page 1 of 1

Lloyd's Register Certificate of Compliance

Office: **Lloyd's Register EMEA**
Copenhagen Design Support Centre, Statutory Section
Strandvejen 104A, 2nd floor
DK-2900 Hellerup
Denmark

Date: **09 May 2012**

This certificate is issued to **DHI Ballast Water Centre, Denmark**

DHI Ballast Water Centre, Denmark

The Document(s) listed in paragraph 1 of the appendix have been examined for compliance with:

- Resolution MEPC.174(58), Annex part 2

and are found to comply from quality assurance and quality control aspects subject to the following:

1.1. It is required to maintain full and accurate log files in order to demonstrate correct quality measures

1.2. The Quality Assurance Project Plan is a project specific document and should as such be subject to review and commenting prior to each project start-up.

1.3. This design appraisal document is to be kept together with quality management plan.

1.4. Subject certificate is valid until 15 June 2015.

1. The documents listed below have been examined

Drawing No.	Rev.	Title	Status	Date
Date: 07 Sep 2011	**2.3**	**Quality Management Plan**	**B**	**09 May 2012**

2. The documents listed below have been considered together with the submitted documents in the appraisal

Drawing No.	Rev.	Title
11810704	**02**	**Quality Assurance Project Plan**

Appraisal Status Key

B Examined and found to comply with §2.2, Part 2 of the annex of IMO Resolution MEPC 174 (58)

Martin Schabert
Statutory Department
Copenhagen Design Support Centre
Surveyor to Lloyd's Register EMEA

LLOYD'S REGISTER EMEA
Lloyd's Register
M. Schabert
COPENHAGEN DESIGN SUPPORT CENTRE

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Form 1124 (2005.02)

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DNV BUSINESS ASSURANCE

MANAGEMENT SYSTEM CERTIFICATE

Certificate No. 109333-2012-AQ-DEN-DANAK

This is to certify that

DHI Group

has been found to conform to the management system standard:

DS/EN ISO 9001:2008

This certificate is valid for the following product or service ranges:

Consulting, software, research & development and laboratory testing, analysis & products within the area of water, environment & health

Locations included in the certification will appear in the appendix.

Place and date:

Hellerup, 2012-03-23

DET NORSKE VERITAS,
BUSINESS ASSURANCE, DANMARK A/S

This certificate is valid until:

2015-01-10

The audit has been performed under the supervision of:

Jan Carsten Schmidt
Lead Auditor

DANAK
SYSTEM Reg.nr. 5001

Jens Peter Høiseth
Managing Director

Lack of fulfilment of conditions as set out in the Certification Agreement may render this certificate invalid.

DNV BUSINESS ASSURANCE

APPENDIX TO CERTIFICATE

This appendix refers to certificate no. 109333-2012-AQ-DEN-DANAK

DHI Group

Locations included in the certification are as follows:

Site Address	Scope:
Agern Allé 5 2970 Hørsholm, Denmark	Consulting, MIKE© by DHI Software Development, Sales & Support, Solutions Software Development, Research, Development & Innovation and Laboratory Analysis, Testing & Products
INCUBA Science Park, Gustav Wieds Vej 10 8000 Århus, Denmark	Consulting, Solutions Software Development and Research, Development & Innovation
Drakegatan 6, 412 50 Göteborg, Sweden	Consulting, MIKE© by DHI Software Sales & Support
Kyrkogatan 3, 222 22 Lund, Sweden	Consulting, MIKE© by DHI Software Sales & Support
Svartmangatan 18, 111 29 Stockholm, Sweden	Consulting, MIKE© by DHI Software Sales & Support
Honnörsgatan 16, Box 3287, 350 53 Växjö, Sweden	Consulting, MIKE© by DHI Software Sales & Support

This certificate is valid until:

2015-01-10

The audit has been performed under the supervision of:

Jan Carsten Schmidt
Lead Auditor

DANAK
SYSTEM Reg.nr. 5001

Place and date:

Hellerup, 2012-03-23

DET NORSKE VERITAS,
BUSINESS ASSURANCE, DANMARK A/S

Jens Peter Høiseth
Managing Director

Lack of fulfilment of conditions as set out in the Certification Agreement may render this certificate invalid.

Accreditation to testing

COPY

DANAK

Company:	**DHI**
	Agern Allé 5 **DK-2970 Hørsholm**
Registration number:	**26**
Valid:	**24-10-2012 to 31-07-2015**

Scope:

Testing

Product

- **Biological items**
- **Chemicals and chemical products**
- **Construction products**
- **Environmental samples**

Test Type

- **Biological and biochemical testing**
- **Chemical testing**
- **Microbiological testing**
- **Ionising radiation and radiochemistry**
- **Sampling**

Testing is performed according to the current list of test methods approved by DANAK.

The company complies with the criteria in EN ISO/IEC 17025:2005 – General requirements for the competence of testing and calibration laboratories and demonstrates technical competence for the defined scope and the operation of a quality management system (refer joint ISO-ILAC-IAF Communiqué dated January 2009, www.danak.dk).

Issued the 24 October 2012

Jesper Høy / **Kirsten Jebjerg Andersen**

In case of any disputes, the Document in Danish language shall have priority.

COPY

DANAK

GOOD LABORATORY PRACTICE

STATEMENT OF COMPLIANCE

Laboratory inspection and study audits for compliance with the OECD Principles for Good Laboratory Practice were carried out at

Laboratory: DHI

on

Dates: 21st and 22nd October 2011

The laboratory inspection and study audits have been carried out in accordance with the regulation settled in Order No. 906 of 14th September 2009 from the Danish Ministry of Environment. The laboratory has been monitored for GLP Compliance within the following scope:

Type of products:

- *Industrial chemicals*
- *Pesticides*
- *Biocides*

Type of tests:

- *Environmental toxicity studies on aquatic and terrestrial organisms.*
- *Studies of behaviour in water, soil and air, bioaccumulation*

The laboratory was found to be operating in compliance with the OECD Principles of Good Laboratory Practice.

Date: 08 August 2012

Jesper Høy
Managing director, DANAK

Kirsten Jebjerg Andersen
GLP inspector, DANAK