UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON D.C. 20460

OFFICE OF THE ADMINISTRATOR
SCIENCE ADVISORY BOARD

[Date]

EPA-**[SAB/CASAC/COUNCIL]-[ADV/COM/CON/LTR]**05-**xxx**

The Honorable Lisa P. Jackson
Administrator
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, N.W.
Washington, D.C. 20460

Subject: Ballast Water Advisory

Dear Administrator Jackson:

This Advisory report responds to a request from EPA's Office of Water (OW) for EPA's Science Advisory Board (SAB) to provide advice on technologies and systems to minimize the impacts of invasive species in vessel ballast water discharge. Vessel ballast water discharges are a major source of non-indigenous species introductions to marine, estuarine, and freshwater ecosystems of the United States. EPA and the U.S. Coast Guard are currently considering changes in ballast water discharge standards. OW requested that the SAB provide advice regarding the effectiveness of existing technologies for shipboard treatment of vessel ballast water, how these technologies might be improved in the future, and how to overcome limitations in existing data. This assessment was conducted by the SAB's Ecological Processes and Effects Committee (EPEC) as augmented with additional panel members having expertise in ballast water issues.

To prepare this report, the EPEC Panel (Panel) reviewed a "Background and Issues Paper" as well as information on 51 existing or developmental ballast water treatment technologies; both were provided by OW. The Panel used this information as the source material for conducting its assessment of ballast water treatment performance using proposed ballast water discharge standards as the performance benchmarks. The Panel held two face-to-face meetings and four teleconferences.

The Panel concluded that five categories of existing ballast water management systems (BWMS) achieved technologically and ecologically significant reductions in organism concentrations and were likely to comply with the least stringent proposed standard (the D-2/Phase 1 standard). However, due to technological, logistical, and personnel constraints imposed by shipboard operations, the Panel also concluded that wholly new treatment systems need to be developed in order to meet more stringent proposed standards (i.e., standards that are 100 x, or 1000 x more stringent than D-2/Phase 1). Finally, the Panel reviewed the many limitations associated with existing data for ballast water treatment performance and provided advice on how to correct these limitations in future assessments. The Panel recommended the implementation of a risk-based systems approach to managing ballast water discharges, use of improved sampling protocols for verifying discharge concentrations, use of surrogate performance measures, development of reliable protocols for compliance monitoring, and further consideration of on-shore reception facilities to treat ballast water discharges.

The SAB appreciates the opportunity to provide EPA with advice on this important topic. We look forward to receiving the agency's response.

Sincerely,

Dr. Deborah Swackhamer
Chair
Science Advisory Board

Dr. Judith Meyer
Chair
SAB Ecological Processes and Effects Committee, Augmented for Ballast Water

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1. EXECUTIVE SUMMARY

Vessel ballast water discharges are a major source of non-indigenous species introductions to marine, estuarine, and freshwater ecosystems of the United States. This Advisory report responds to a request from EPA's Office of Water (OW) for EPA's Science Advisory Board (SAB) to provide review and advice regarding the effectiveness of existing technologies for shipboard treatment of vessel ballast water, how these technologies might be improved in the future, and how to overcome limitations in existing data. This report constitutes a *de novo* assessment conducted by the SAB's Ecological Processes and Effects Committee (EPEC) as augmented with additional panel members having expertise in ballast water issues. In addition to this Panel's assessment of ballast water management systems (BWMS), EPA's OW and the USCG have commissioned the National Academy of Sciences (NAS) to conduct a complementary study that assesses the risk of successful invasions as a function of different levels of organisms in ballast water discharges. The NAS study is ongoing and is expected to be completed May 31, 2011.

To prepare this Advisory report, the EPEC Panel (Panel) reviewed a "Background and Issue Paper" written by EPA's OW. This paper provided an overview of information about major categories of shipboard ballast water treatment technologies and presented proposed ballast water discharge standards drawn from international sources, the US Coast Guard (USCG), and nine states. In addition, EPA's OW compiled information on 51 existing or developmental ballast water treatment technologies. The Panel used this information as the source material for conducting its assessment of ballast water treatment performance and, as requested by EPA, used proposed ballast water discharge standards as the performance benchmarks.

The EPEC Ballast Water Advisory Panel met on July 29 – 30, 2010, to receive briefings from EPA's OW, to hear public comments, and to begin discussing the charge questions. Teleconferences were held on Oct. 26 and Nov. 4, 2010, to discuss preliminary texts prepared by individual subgroups of the Panel and to hear public comments. The full Panel met again on Jan. 25 -26, 2011, to discuss the compiled draft report, and to discuss preliminary conclusions and recommendations. Two additional teleconferences were held on March 15 – 17, 2011, to discuss final revisions to the draft report.

The Panel concluded that five categories of existing ballast water management systems (BWMS) achieved technologically and ecologically significant reductions in organism concentrations and were likely to comply with the least stringent proposed standard (the D-2/Phase 1 standard). However, due to technological, logistical, and personnel constraints imposed by shipboard operations, the Panel also concluded that wholly new treatment systems need to be developed in order to meet more stringent proposed standards (i.e., standards that are 100 x, or 1000 x more stringent than D-2/Phase 1). Finally, the Panel reviewed the many limitations associated with existing data for ballast water treatment performance and provided advice on how to correct these limitations in future assessments. The Panel recommends the implementation of a risk-based systems approach to managing ballast water discharges, use of improved sampling protocols for verifying discharge concentrations, use of surrogate performance measures, development of reliable protocols for compliance monitoring, and consideration of on-shore reception facilities to treat ballast water discharges.

Regulatory context

Ballast water discharges are regulated by EPA under authority of the Clean Water Act (CWA) and by the U.S. Coast Guard (USCG) under authority of the National Invasive Species Act (NISA). In December 2008, US EPA issued a Vessel General Permit (VGP) for discharges incidental to the normal operation of commercial vessels, including ballast water discharges. The VGP sets effluent limits for ballast water that rely on "best management practices" (primarily use of ballast water exchange, or BWE) and do not include a numeric discharge limit. The VGP expires on Dec. 19, 2013. For subsequent iterations of the VGP, the EPA has stated its intention to establish best available technology (BAT) standards for the treatment of ballast water, once such technologies are shown to be commercially available and economically achievable.

Existing USCG rules governing ballast water also primarily rely on BWE. In August 2009, the USCG proposed revisions to their existing rules to establish numeric concentration-based limits for viable organisms in ballast water. The proposed USCG rule would initially require compliance with a "Phase 1" standard, followed by "Phase 2" rules that set concentration limits at 1000 times more stringent than Phase 1 standards for viable organisms > 10 microns in minimum dimension. Phase 2 standards also set concentration limits for bacteria and viruses. Neither Phase 1 nor Phase 2 standards have been finalized. The USCG Phase 1 standards have the same concentration limits as do regulations set out in 2004 by the International Convention for the Control and Management of Ships' Ballast Water and Sediments. The US is not a Party to the Treaty, nor has the Treaty yet entered into force internationally. However, these standards (known as IMO-D2), are the *de facto* international standard. In general, manufacturers of ballast water treatment technologies have designed their equipment to meet these IMO-D2 standards.

Ballast water management should be implemented using a risk-based systems approach

A ballast water management strategy to decrease the rate of successful invasions by nonindigenous species should be part of an overall plan for the reduction of invasion events, monitoring, containment, and eradication. Emphasis only on one aspect, the initial invasion event, is not likely to reduce the risk of invasions to an acceptable probability. Decisions on approaches to ballast water management can be viewed in the framework of risk assessment. The risk assessment process should: (1) should recognize the stochastic and non-linear, nature of the invasion process, (2) clearly define the management goals, and (3) evaluate the effectiveness of BWMSs within the context of other sources of nonindigenous species and other organism found on the vessel, in the treatment system, and with respect to specific receiving habitats.

Rigorous sampling and statistical verification of performance is essential

The Panel was asked to respond to charge questions that focused primarily on whether test data demonstrated that BWMS met or "closely approached" proposed standards for discharge and whether they did so "credibly" and "reliably." As benchmarks for performance, the Panel was asked to use proposed numerical standards as well as narrative descriptions such as "no living organism," "sterilization," and "zero or near zero" discharge. In order to place its assessments of treatment performance in appropriate scientific context, the Panel first had to consider the statistical and sampling issues prerequisite to being able to state with statistical confidence that these numerical and narrative benchmarks could be met. With regard to detecting whether or not treated ballast water meets a stated standard in terms of the density of viable organisms of any size class in a ship's ballast water, "zero detectable discharge" initially seems a desirable standard to achieve. However, when organism concentrations are close to the performance standard, a single sample may require too large a volume of water to be logistically feasible. Further, when small sample volumes are collected, the probability of detecting an organism is low even when actual organism concentration are relatively high; for example, statistical analyses show that organisms will be detected in fewer than 10% of subsamples if a 1-L sample is taken and the "true" concentration is 100 organisms m^{-3}. This illustrates that when no organisms are detected from a relatively small sample, the true concentration in the ballast tank may be large – it depends on the sample volume collected and these errors are much larger for small sample volumes.

The Panel concludes that without a well-defined, rigorous sampling protocol, any standard, no matter how stringent, will be difficult to assess and defend. Furthermore, it will be impossible to compare the effectiveness of different BWMSs without rigorous protocols. These sampling protocols should include consideration of the spatial distribution of plankton in ballast water. The Poisson distribution is recommended as the model for statistical analysis of treated water samples.

The Panel also concludes that the D-2/Phase 1 performance standards for discharge quality are currently measurable, based on high quality procedures for land-based and shipboard testing. However, available methods to test D-2/Phase 1 compliance are presently at or near analytic detection limits for the two largest organism size classes. Further, due to the logistics of collecting, reducing, and counting organisms in all size classes within the volumes of water required to achieve a standard 1000x more stringent than the IMO/Phase 1 performance standard, a 1000x more stringent standard is impracticable. A standard 10x more stringent may be possible, but it seems unlikely, for the reasons mentioned above, that a 100x more stringent standard can be achieved. New or improved methods will be required to increase detection limits. The Panel notes these conclusions pertain to evaluating data from land-based and shipboard testing, though the same statistical theory and practice applies to compliance testing by port state control officers. Finally, statistical conclusions at a stated confidence level always have an associated error probability, thus, "100% certainty" is not statistically possible.

Charge question 1: Performance of shipboard systems with available effluent testing data

1. a. *For the shipboard systems with available test data, which have been evaluated with sufficient rigor to permit a credible assessment of performance capabilities in terms of effluent concentrations achieved (living organisms/unit of ballast water discharged or other metric)?*

The Panel found that five categories of BWMSs had been evaluated with sufficient rigor to permit a credible assessment of performance capabilities: Deoxygenation + cavitation; Filtration + chlorine dioxide; Filtration + UV; Filtration + UV + TiO2; Filtration + electro-chlorination. The Panel concluded that these five BWMS categories have been demonstrated to meet the IMO

D-2 discharge standard, when tested under the IMO G8 guidelines, and will likely meet USCG Phase 1standards, if tested under EPA's more detailed Environmental Technology Verification (ETV) protocols.

1. *b. For those systems identified in (1a), what are the discharge standards that the available data credibly demonstrate can be reliably achieved? Furthermore, do data indicate that certain systems (as tested) will not be able to reliably reach any or all of the discharge standards shown in that table?*

Detection limits for currently available test methods and approaches prevent a complete statistical assessment of BWMS' ability to meet stricter discharge standards. However, available data suggests that the same five BWMS types may be able to reach 10x D-2/Phase 1for the > 50 μm and 10 – 50 μm size classes sometime in the near future, if both treatment performance and testing approaches improve. Available data also indicates that no current BWMS can meet the USCG Phase 2 standard, particularly for categories such as total bacteria. It is not possible to predict which systems will be unable to reach any or all of the other discharge standards because the only reliable data available to the committee were on BWMSs that were tested specifically for D-2 discharge standards, and failures to meet D-2 (or any other standards) are typically not reported.

1. c. *For those systems identified in (1a), if any of the system tests detected "no living organisms" in any or all of their replicates, is it reasonable to assume the systems are able to reliably meet or closely approach a "no living organism" standard based on their engineering design and treatment processes?*

The Panel concluded that it is not reasonable to assume that BWMS are able to reliably meet or closely approach a "no living organism" standard. Available data demonstrates that current BWMS do not achieve sterilization or the complete removal of all living organisms.

Charge question 2: Potential performance of shipboard systems without reliable testing data

2. *Based on engineering design and treatment processes used, and shipboard conditions/constraints, what types of ballast water treatment systems can reasonably be expected to reliably achieve any of the proposed standards, and if so, by what dates? Based on engineering design and treatment processes used, are there systems which conceptually would have difficulty meeting any or all of the proposed discharge standards?*

The Panel found that nearly all of the 51 BWMS treatment categories evaluated are based on reasonable engineering designs and treatment processes, and most are adapted from long-standing industrial water treatment approaches. However, the lack of detailed information on the great majority of BWMSs precludes an assessment of limitations in meeting any or all discharge standards. In particular, the Panel determined that the following data essential to future assessments: documentation that test protocols were followed; documentation that rigorous QA

/QC methods were followed; and full reporting of all test results. At present, vendors are not required to report test failures.

Although several BWMSs appear to safely and effectively meet D-2/Phase 1 discharge standards, the Panel notes that factors beyond mechanical and biological efficacy need to be considered as BWMS technology matures. Several parameters will affect the performance or applicability of individual BWMSs to the wide variety of vessel types that carry ballast water. These include environmental parameters (e.g., temperature and salinity), operational parameters (e.g., ballasting flow rates and holding times), and vessel design characteristics (e.g., ballast volume, ballasting rates, and unmanned barges).

Charge question 3: System development

3 a. For those systems identified in questions 1 a. and 2, are there reasonable changes or additions to their treatment processes which can be made to the systems to improve performance?

The development cycle of a given BWMS appears to stop once testing indicates that the D-2 standard has been met. There are reasonable changes, requiring additional expense and complexity, that could provide incremental improvements in efficacy. The following comments on possibilities to improve performance do not consider possible ship-board constraints (discussed below):

- **Deoxygenation + cavitation**. Severe hypoxia ([O_2] <1 mg/L) has already been established in these systems and in and of itself, cannot be improved upon. Improvements may emerge by shortening the time to severe hypoxia and increasing hold time. In addition, increasing the degree of cavitation may increase performance by greater mixing and thus exposure of organisms to severe hypoxia.
- **Mechanical separation + oxidizing agent**. Separation (i.e., physical removal of organisms) could be optimized and contact time for oxidizing agent exposure could be increased.
- **Mechanical separation + UV.** Separation could be optimized and contact time/dosage with UV could be increased.

Combinations of some technologies above may result in improved performance, and the Panel recommends that trials be conducted to determine optimum combinations. “Tweaking” existing technologies, however, will only result in incremental improvements toward meeting published standards. New technologies will be needed for 100x and 1000x IMO regulations, and shipboard systems should not be the only possibilities considered (see response to charge question 4, Section 6). New approaches, possibly from the wastewater treatment industry, may achieve those more stringent standards, but will take time to develop and trial to determine practicality and cost impacts. More stringent standards also increase the importance of process control.

A systems approach to ballast-water management is recommended. Doing so will significantly increase the operational burden on ship operators and will be technically challenging, but feasible in most cases.

3. b. Part A. What are the principal technological constraints or other impediments to the development of ballast water treatment technologies for use onboard vessels to reliably meet any or all of the discharge standards?

We list here principal constraints and impediments.

- Ship-board ballast water treatment technologies are developing rapidly. The focus to date has been on engineering the technology. Less consideration has been given to the following, which are equally important: training, operation, maintenance and repair, and monitoring effectiveness.

- With regard to monitoring effectiveness, zero detectable live organisms in the discharge is an unrealistic and unattainable goal. The complexity of the systems and the difficulties associated with counting live organisms, particularly the smaller size classes, combine to limit our ability to measure improvements to levels 100x and 1000x IMO.

- Facilities at which technologies may be tested are few, and there is a strong need to increase sharing of data and specific protocols among them.

- There is no established compliance, monitoring, and enforcement regime which will focus development of future technologies. To our knowledge, none are available; incentives for technology development are dampened.

- There is disagreement on discharge standards; they vary domestically, i.e., from state to state within the USA, and internationally, making it difficult for manufacturers to meet a target standard.

Despite the constraints listed above, we note that successful systems will, as described by Glosten—Herbert--Hyde (2002):

1) meet the demands of the shipboard marine environment

2) minimize operational changes to the vessel's existing ballast management systems

3) fit within the normal and existing operational procedures of shipboard personnel

4) minimize initial capital and life-cycle costs

5) meet the existing safety standards of the industry, regulatory bodies and the target vessel operating company.

3. b. 2. *What recommendations does the SAB have for addressing these impediments/constraints?*

- It should not be assumed that onshore systems can transfer straightforwardly to ships.

- Vessels are initially designed with ballasting capabilities and procedures that match their intended service and voyage profile. In retrofitting vessels for ballast-water treatment, the system(s) employed ideally will fit within those original parameters and minimize disruption.

- Ships' crews are small in number and busy; therefore, any new system must be easy to operate, maintain, and ideally be remote controlled from the ballast-control console and operate automatically in or near port.
- A treatment system's full cost includes not only its initial purchase and installation, but its operational costs over the long term as well.
- The treatment system should pose no unreasonable health risk for the crew, not create a higher risk for vessel safety, and require no exception to the vessel owner's safety procedures. The equipment installation and operation procedures must also meet Classification Society, Flag State, and Port State control authorities' requirements.

Finally, the Panel recommends that shipboard constraints to ballast-water treatment technologies need to be considered relative to potential increased usage of shore-based treatment facilities.

b. Part B. Are these impediments more significant for certain size classes or types of organisms (e.g., zooplankton versus viruses)? Can currently available treatment processes reliably achieve sterilization (no living organisms or viable viruses) of ballast water onboard vessels or, at a minimum, achieve zero or near zero discharge for certain organism size classes or types?

1. Shipboard impediments apply to all size classes of organisms and indicator microbes. Some treatment systems or combinations of systems, however, are more effective with larger organisms and some with unicellular organisms. The technology exists to remove nearly all organisms >50 µm from discharged water.

2. Given the volumes of water involved, onboard sterilization of ballast water is not possible using current technologies. Furthermore, the assurance of sterilization is impossible to verify.

3. There is no assurance of zero or near zero discharge. That value is not measureable in a scientifically defensible way and cannot presently be verified at "end of pipe" for a working ship.

4. The current filter and disinfect approach may not be adequate to meet more stringent standards. Treatment processes will need to become multistage and part of an integrated ballast water management effort (see response to charge question 4).

5. Meeting increasingly stringent performance standards will require that BWMS perform nearly perfectly, nearly all of the time. Existing ship ballast water management systems and practices do not support this level of control or performance; a fundamental shift in system design and operational practices would be needed.

Charge question 4: Development of reliable information

4. *What are the principal limitations of the available studies and reports on the status of ballast water treatment technologies and system performance and how can these limitations be*

overcome or corrected in future assessments of the availability of technology for treating ballast water onboard vessels?

The Panel found that existing information about ballast water treatment is limited in many respects, including significant limitations in data quality, shortcomings in current methods for testing BWMS and reporting results, issues related to setting standards and for compliance monitoring, and issues related to test protocols and use of surrogate indicators. The Panel provides its findings and recommendations for these issues below.

More broadly, however, the Panel found that data on the effectiveness of practices and technologies other than shipboard ballast water treatment systems are woefully inadequate because insufficient attention has been given to integrated sets of practices and technologies including (1) managing ballast uptake to reduce presence of invasives, (2) reducing invasion risk from ballast discharge through operational adjustments and changes in ship design to reduce or eliminate need for ballast water, (3) development of voyage-based risk assessments and application of HACCP principles to ballast water management, and (4) options for on-shore treatment of ballast water. The Panel concludes that combinations of practices and technologies should be considered as potentially more effective and potentially more cost-effective approaches than sole reliance on shipboard ballast water treatment technology. The Panel notes the critical role of compliance monitoring and recommends that EPA develop metrics appropriate for compliance monitoring and enforcement as soon as possible.

Principal limitations of available data and protocols

- Data are not sufficiently compatible to compare rigorously across ballast water treatment systems because standard protocols for testing ballast water treatment systems have been lacking. ETV protocols will improve this situation.

- No international requirement exists to report failures in type approval testing. On the basis of typically reported results, therefore, it is impossible to draw reliable conclusions about the consistency or reliability of BWMS.

- The important size classes $\leq$ 10 µm previously have been ignored in developing guidelines and standards.

- Clear definitions and direct methods to enumerate viable organisms in the specified size classes at low concentrations are missing for some size classes and indicator organisms and logistically problematic for all size classes, especially nonculturable bacteria, viruses, and resting stages of many other taxa.

Alternatives to shipboard treatment of ballast water

- Data on the effectiveness of practices and technologies other than shipboard ballast water treatment systems are woefully inadequate because insufficient attention has been given to integrated sets of practices and technologies including (1) managing ballast uptake to reduce presence of non-indigenous species, (2) reducing invasion risk from ballast discharge through operational adjustments and changes in ship design to reduce or eliminate need for ballast water, (3) development of voyage-based risk assessments and / or HACCP principles, and (4) options for on-shore treatment.

- Onshore treatment of ballast water is technically feasible, and screening-level economic estimates suggest that it is at least as economically feasible as shipboard treatment. Equipment, operational, and logistical challenges will need to be overcome and facilities designed to minimize impact on vessel revenue.

- Onshore treatment is likely to be safer, more reliable and more adaptable than shipboard treatment.

- The effort and cost of monitoring and enforcement needed to achieve a given level of compliance is likely to be much less for a relatively small number of on-shore treatment plants compared to approximately 300 times as many shipboard plants.

- The current regulatory framework provides little incentive for development of onshore treatment facilities.

To overcome present limitations, we recommend that:

- Testing of BWMSs in a research and development mode should be distinct from testing for type approval.

- Type approval testing should be conducted by a party independent from the manufacturer with appropriate, established credentials, approved by EPA/USCG.

- Reported results from type approval testing of BWMS should include failures as well as successes during testing so that the reliability of systems can be judged. This would be aided by the adoption of a transparent international standard format for reporting, including specification of QAQC protocols.

- Infectious viruses should not be included in standards for BTWSs until new technology becomes commercially available that reliably distinguishes infectious from non-infectious agents.

- Complete test results for ballast water treatment systems, including failures, be reported and considered in certification decisions.

- Testing protocols should be internationally comparable and, ideally, applied across the full gradient of environmental conditions represented by the Earth's ports, and use natural sources of water, including natural salinity, DOC, etc.

- Protist-sized organisms should be included in ballast water standards, and therefore in protocols to assess the performance of ballast water treatment systems.
- Testing protocols diverge from those recommended by the ETV report for the components highlighted in Table 6. 4.

- Protocols be developed to identify suitable standard test organisms surrogate taxa and surrogate parameters to complement or replace metrics that are logistically difficult or infeasible for estimating directly the concentration of living organisms.

- Use of representative "indicator" taxa (toxic strains of *Vibrio cholerae*; *Escherichia coli*; intestinal enterococci) should continue to be used as a sound approach to assess BWMSs for effective removal of harmful bacteria. These estimates will be improved when reliable techniques become available to account for active, nonculturable cells as well as culturable cells.

- Laboratory bench (small scale) tests should be used as a sound first step in assessing BWMS performance because they enable controlled testing over a full range of environmental and biological conditions and help to identify limitations or critical flaws in the system design while minimizing logistical difficulties, expense, and risks. As a second step, tests should be conducted in mesocosms (intermediate scale) because they enable testing under more realistic conditions in checking treatment performance prior to full-scale, land-based testing.

- As a critical part of the BWMSs, EPA should develop metrics appropriate for compliance monitoring and enforcement as soon as possible.

- Combinations of practices and technologies should be considered as potentially more effective and potentially more cost-effective approaches than reliance on one ballast water treatment technology. For example, ship-specific risk assessments (based on the environment and organisms present in previous ports of call) could be used to help prioritize the use of risk management practices and technologies, as well the targeting of compliance and enforcement efforts.

- EPA should encourage the development of an ISO standard for type approval testing of BWMS.

- EPA should conduct a comprehensive analysis addressing cost, operations, and safety associated with on-shore Facilities, identify vessel-fleet to ports-of-call networks that would most benefit from a Facility approach, and develop a pilot program(s) for one or more of these networks to assess challenges and develop solutions.

- EPA should develop programs that will relieve the systemic barriers to the implementation of Facility-based ballast water management.

- EPA should conduct further study of the efficacy and costs of onshore treatment. If the evidence indicates that onshore treatment is both economically and logistically feasible and is more effective than shipboard treatment systems, it should be used as the basis for assessing the ability of available technologies to remove, kill, or inactivate living organisms to meet a given discharge standard. In other words, onshore treatment may enable ballast water discharges to meet a stricter standard.

2. INTRODUCTION

2.1 Background

EPA's Office of Water (OW) requested that the Science Advisory Board (SAB) conduct an assessment of the performance of shipboard ballast water mansagement systems (BWMS) and provide advice on how BWMS performance could be improved. The SAB based its assessment and advice on information provided by OW, including the document "Availability and Efficacy of Ballast Water Treatment Technology: Background and Issue Paper",June 2010, and a compilation of available information and data on BWMS systems (as described in Appendix 1 and Section 3 of this report).

Vessel ballast water discharges are a major source of nonidigenous species introductions to marine, estuarine, and freshwater ecosystems of the United States. Ballast water discharges are regulated by EPA under authority of the Clean Water Act (CWA) and regulated by the U.S. Coast Guard under authority of the National Invasive Species Act (NISA). NISA generally requires vessels equipped with ballast water tanks and bound for ports or places in the United States after operating beyond the U.S. Exclusive Economic Zone to conduct a mid-ocean ballast water exchange, retain their ballast water onboard, or use an alternative environmentally sound ballast water management method approved by the U.S. Coast Guard. Under the authority of the CWA, EPA's Vessel General Permit, in addition to the mid-ocean exchange, requires the flushing and exchange of ballast water by vessels in Pacific near-shore voyages and saltwater flushing of ballast water tanks that are empty or contain only un-pumpable residual ballast water.

While useful in reducing the presence of potentially invasive organisms in ballast water, ballast water exchange and saltwater flushing have variable effectiveness and may not always be feasible due to vessel safety concerns. On August 28, 2009, the U.S. Coast Guard proposed establishing standards for concentrations of living organisms that can be discharged in vessel ballast water (74 FR 44632), and some States have established standards of their own. In addition, a number of studies and reports have been published on the status and efficacy of ballast water treatment technologies, and data on the efficacy of certain systems are available.

The EPEC Ballast Water Advisory Panel met on July 29 – 30, 2010, to receive briefings from EPA's OW, to hear public comments, and to begin discussing the charge questions. Teleconferences were held on Oct. 26 and Nov. 4, 2010, to discuss preliminary texts prepared by individual subgroups of the Panel and to hear public comments. The full Panel met again on Jan. 25 -26, 2011, to discuss the compiled draft report, and to discuss preliminary conclusions and recommendations. Two additional teleconferences were held on March 15 – 17, 2011, to discuss final revisions to the draft report.

2.2 Charge to the Panel

Charge question 1: *Performance of shipboard systems with available effluent testing data*

2. a. For the shipboard systems with available test data, which have been evaluated with sufficient rigor to permit a credible assessment of performance capabilities in terms of effluent concentrations achieved (living organisms/unit of ballast water discharged or other metric)?

2. b. For those systems identified in (1a), what are the discharge standards that the available data credibly demonstrate can be reliably achieved (e.g., any or all of the standards shown in Table 1 of the White Paper? Furthermore, do data indicate that certain systems (as tested) will not be able to reliably reach any or all of the discharge standards shown in that table?

4. c. For those systems identified in (1a), if any of the system tests detected “no living organisms” in any or all of their replicates, is it reasonable to assume the systems are able to reliably meet or closely approach a “no living organism” standard or other standards identified in Table 1 of the White Paper, based on their engineering design and treatment processes?

Charge question 2: *Potential performance of shipboard systems without reliable testing data*

5. Based on engineering design and treatment processes used, and shipboard conditions/constraints, what types of ballast water treatment systems (which may include any or all the systems listed in Table 4 of the White Paper) can reasonably be expected to reliably achieve any of the standards shown in Table 1 of the White Paper, and if so, by what dates? Based on engineering design and treatment processes used, are there systems which conceptually would have difficulty meeting any or all of the discharge standards in Table 1 of the White Paper?

Charge question 3: System development

3 a.For those systems identified in questions 1 a and 2, are there reasonable changes or additions to their treatment processes which can be made to the systems to improve performance?

3. b. 1. What are the principal technological constraints or other impediments to the development of ballast water treatment technologies for use onboard vessels to reliably meet any or all of the discharge standards presented in Table 1 of the White Paper?

3. b. 2. What recommendations does the SAB have for addressing these mpediments/constraints?

3. b. 3.Are these impediments more significant for certain size classes or types of organisms (e.g., zooplankton versus viruses)?

3. b. 4. Can currently available treatment processes reliably achieve sterilization (no living organisms or viable viruses) of ballast water onboard vessels or, at a minimum, achieve zero or near zero discharge for certain organism size classes or types?

Charge question 4: Development of reliable information

4. What are the principal limitations of the available studies and reports on the status of ballast water treatment technologies and system performance and how can these limitations be overcome or corrected in future assessments of the availability of technology for treating ballast water onboard vessels?

2.3. Management Context and Glossary of Key Phrases

2.3.1. Ballast water regulations

U.S. Federal rules

In December 2008, US EPA issued a Vessel General Permit (VGP) for discharges incidental to the normal operation of commercial vessels, including ballast water, as authorized under the Clean Water Act (CWA). The VGP set technology-based effluent limits for ballast water that rely on "best management practices" (primarily use of ballast water exchange, or BWE) and do not include a numeric discharge limit. The VGP expires on Dec. 19, 2013.

Existing US Coast Guard (USCG) rules governing ballast water, as authorized under the National Invasive Species Act (NISA), also primarily rely on ballast water exchange. Though the BWE provisions are not identical, the general principle of BWE as used by EPA and USCG is very similar. In August 2009, the USCG proposed revising their existing rules to establish numeric concentration-based limits for organisms in ballast water. The proposed rule would initially require compliance with a "Phase 1 standard" that has the same concentration limits as the IMO D-2 standard (see below) and subsequently require compliance with a "Phase 2 standard" that is 1000 times more stringent for organisms that are more than 10 microns in minimum dimension, and that also contains concentration limits for bacteria and viruses. The USCG has not finalized this rule, and in the meantime continues to require use of BWE. (Iris note: (where does the 100 x more stringent rule come in, or does it?

In recent years, Congress has considered but not enacted legislation that would directly set concentration-based ballast water discharge standards.

Other Regulatory Frameworks

U.S. States:

Under the CWA, U.S. states have the authority to impose their own ballast water discharge standards through the CWA section 401 certification process applicable to Federally-issued "NPDES" permits such as the VGP. A number of States have exercised that authority by setting numeric limits for ballast water discharges into their waters and these numeric limits are included as a condition in the VGP. In addition, several states (e.g. California and some Great Lakes states) have enacted their own independent State laws to establish ballast water treatment standards. Thus, in practice, EPA's VGP standards establish the minimum standard (or "floor") for ballast water discharges, but States retain and have exercised their authority to set standards that are more stringent.

International standards / treaties:

The International Convention for the Control and Management of Ships' Ballast Water and Sediments ("IMO Ballast Water Convention"), adopted by the International Maritime Organization ("IMO") in February 2004, contains concentration-based limits on organisms in ballast water set out in its Regulation D-2. The treaty will not come into force unless it is ratified by additional countries; and implementation would then require the enactment and enforcement of appropriate laws or regulations by the countries that are party to the treaty. However, equipment manufacturers are currently designing and testing equipment to meet the D-2 standards. These and the other main concentration-based limits for organisms in ballast water that have been proposed or adopted are shown in Table 2.1.

Table 2.1 The range of concentration-based limits proposed or adopted for organisms in ballast water: "US Negotiating Position" is what the U.S. argued for in the negotiations on discharge standards for the IMO Ballast Water Convention. "California Interim" and "California Final" standards refer to the concentration limits enacted by the State of California in 2006. "No detectable" means "no detectable living organisms" the standard written into the California law. The California Final standard does not specify health protective limits, but since the standard for all bacteria is "no detectable," the standard for any bacterial species or groups of species must be "no detectable" as well.

A. Concentration limits for four organism classes

	Organisms >50 µm in minimum dimension	**Organisms 10-50 µm in minimum dimension**	**Bacteria**	**Viruses**
	per m^3	**per ml**	**per ml**	**per ml**
IMO D-2	10	10	no limit	no limit
USCG Phase 1	10	10	no limit	no limit
US Negotiating Position	0.01	0.01	no limit	no limit
USCG Phase 2	0.01	0.01	10	100
California Interim	no detectable	0.01	10	100
California Final	no detectable	no detectable	no detectable	no detectable

B. Public health protective concentration limits

	Toxicogenic *Vibrio cholerae*	***Escherichia coli***	**Intestinal enterococci**
	per ml	**per ml**	**per ml**
IMO D-2	.01	2.5	1

USCG Phase 1	.01	2.5	1
US Negotiating Position	.01	1.26	0.33
USCG Phase 2	.01	1.26	0.33
California Interim	.01	1.26	0.33
California Final	no detectable	no detectable	no detectable

2.3.2. **Applying Risk Assessment Principles to Ballast Water Management**

The purpose of this section is to explore the use of risk assessment to put strategies for treatment of ballast water into a probabilistic decision-making process. This process should be applied to the entire system of ballast water management and not to just one technique, device or practice. Each step of the process, from taking on ballast water at the port of origin to its discharge into the receiving port, is dependent upon the others. Included in this system is also the regulatory environment, the training of the personnel, quality control, and environmental sampling.

Risk Assessment]

The establishment of a nonindigenous species is the joint probability of how often the species would be introduced, of the initial population size necessary to ensure reproduction, and of the probability that the organisms would find a suitable environment for propagation. This joint probability is low for any one species or specific shipping event. However, a large number of species can be transported via ship, and thousands of ships arrive at U. S. ports, making the probability of an nonindigenous or a new pathogen becoming established a substantial probability. Given that shipping is a major industrial activity that will continue indefinitely, even a small probability for each ship and for each species, will result in successful invasions. The goal of a ballast water management (BWM) program is to lower that probability, especially for particularly damaging species and pathogens. For a BWM program to be successful, the goals need to be specific and measureable, and the operational context needs to be understood. First a model of the relationship between the number of organisms in ballast water and the likelihood of invasion or infection by a pathogen needs to be derived.

1. Probabilistic approach to deriving risk due to nonindigenouss

A foundation for the risk assessment for invasive species has been established (Drake 2004, 2005, Landis 2004). The process is density dependent, with an increase in the density leading to an increase in population growth rate (Drake 2004). Modelling has also demonstrated the importance of a beachhead effect, where a population increases in a relatively isolated habitat patch before spreading to the remainder of the environment (Deines et al 2005). Both Drake (2005) and Deines et al (2005) recognize the importance of eliminating the organisms during the initial invasion event or destroying the beachhead in order to implement control.

Deines et al (2005) used spatially explicit stochastic difference models and Drake and Lodge (2006) employed stochastic differential equations to model invasion events. In both studies the importance of understanding the stochastic aspects of colonization, the initial population size (propagule pressure) and density dependent effects on population growth were important in determining the probability of invasion. The actual dynamics of invasions were sensitive to initial conditions. The combination of stochastic and non-linear components results in a distribution of outcomes in both studies. This means that any relationship between propagule pressure and probability of invasion will be a distribution of outcomes. These foundations have been used to estimate risk in case studies (Drake et al 2006, Obery and Landis 2007). A risk assessment for managing ballast water invasion should have as its foundation the stochastic-non-linear nature of the invasion process.

2. Propagule pressure and invasion relationships

It is possible to derive relationships between the number of organisms with an invasive potential (propagules) and the probability of an invasion over a specified amount of time. Such a relationship is described by Figure 1A. It is assumed that the greater the number of propagules, the greater the probability of the establishment of an invasive potential. In this instance it is assumed that the relationship is sigmoidal and has a threshold, but a number of curves could be possible and may be specific to the type of organism or environment. The solid line represents the central tendency of the relationship with the dashed lines representing confidence intervals. Note that the confidence intervals include a successful invasion even without propagule pressure from ballast water and also the likelihood of no invasion even with organisms escaping. After all, organisms can come from a variety of sources other than ballast water.

Figure 1B describes a process for setting targets for the number of organisms in ballast water. First a policy decision is made about an acceptable frequency of successful invasion over a specified amount of time. Reading across the graph to where this rate intersects with the concentration-response curve gives the numbers of organisms corresponding to the low, expected and high values. Trade-offs can then be made on the likelihood of success in meeting the specification and the costs of achieving the goal.

Although these graphs were drawn to express the relationship with one species of concern, similar plots may be derived for discharges with a large number of species. The greater the diversity of species, the larger the probability of an invasion by at least one.

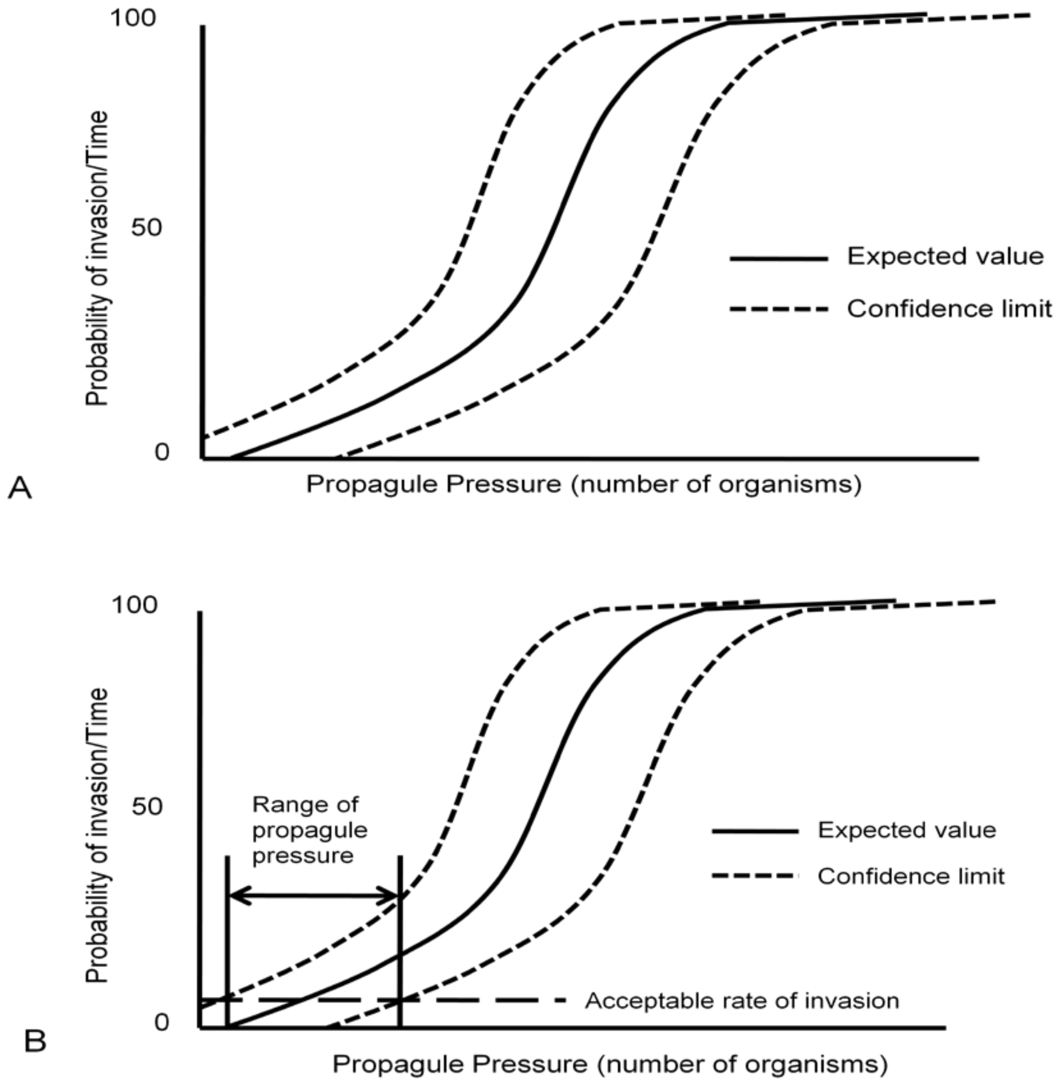


Figure 1. Relationship between propagule pressure (concentration) and the probability of an invasion by that species over time. The confidence intervals around the expected probability describe the uncertainty in the relationship (Figure 1A). Such a curve will allow a quantitative determination of suitable goals for reducing potential nonindigenouss from ballast water. Once a level of probability is agreed upon, the corresponding values of propagule pressures likely to produce the result can be obtained.

3. Ballast water management goals and the decision making, risk assessment context

In order to evaluate the various types of BWMSs, it is important to understand how they fit into a decision-making context. This means that the management goal has to be clearly defined as in the above graphical model. Additionally, the effectiveness of the ballast-water treatment has to be evaluated within the context of a ship with cargo, human food and waste, and many organisms attached to the hull. The sea chest (a portion of the ship where seawater can be loaded or discharged) can also be a source of nonindigenous speciess. There is also the possibility of human error in the treatment process that may lead to the escape of organisms or the release of toxic materials. Each of these items will be covered in the paragraphs below.

4. The goal: what does "zero" mean?

What does "zero" discharge of nonindigenous species and other organisms mean as a goal, since such a value is essentially not measureable (see section XX)? The volumes to be sampled are enormous, there are refugia from treatment within the ballast water tanks, and the discharge is into an environment with multiple sources of invasive species. Operational definitions may prove more useful in making a decision about ballast water treatment options.

Operational definitions are very important. For example, does "zero" mean that a discharge from a specific ship will contain no organisms that will colonize or infect a port environment for that one particular combination of disinfection treatment and vessel discharge? This is a very specific criterion but it is not necessarily protective. Furthermore, given the logistics needed to sample and enumerate organisms in a discharge, it will not be possible to meet this requirement for every discharge of every ship.

On the other hand, "zero" could mean that the treatment technology or system will prevent the introduction of a harmful invasive organism or disease to that port over a ten-year period. This is a very different criterion, a performance-based requirement that states the goal (no invasion or infection) over a specified time frame. Individual treatments on certain ships may fail, but an overall system would ensure that any colonizing organisms were quickly eradicated or that other methods would be employed to prevent their propagation. These two "zero" goals are very different and each puts on-board or land-based treatment options into specific and differing contexts. In order to rank the various technologies and treatment systems, therefore, the specific goals of the program need to be carefully defined.

There is also the question of specific goals for the protection of the port from nonindigenous species and pathogens. Are there specific requirements for each category of organism or is a combination approach going to be attempted? Let us take pathogenic organisms as an example. In ballast water, a large proportion of the organisms are likely to not be pathogenic, but the human welfare implications may be higher for the pathogenic organisms. Is the goal protection against human pathogens or those pathogens that may infect shellfish and fish populations, destroy important sea grass beds, or other segments of the ecological structure of the receiving port? Depending upon the specific policy goals, different propagule pressure-infection relationships may need to be considered.

As the specifications for the treatment process are made, it is also important to understand the context of a ship and its port facility. Ballast water would only be one of the potential sources of nonindigenous species and pathogens brought by a vessel.

5. Context of a cargo or tanker ship and the port facility

The ship has more than ballast water as a source of invasive species. Ships contain cargos of varied types, crew, food, human waste, and hull fouling organisms. The port facility may also contain a variety of other vessels that may be sources of nonindigenous species and pathogens. Understanding the efficacy of the treatment program needs to be placed into this broader context.

Cargo may contain insects, fungi, seeds and spores that may be released to the environment as the cargo is unloaded or transported. Food can be another source of nonindigenous species, especially if living organisms are transported. Human waste can be a source of pathogens, but can be disposed of using appropriate facilities. Fouling of a ship's hull can be a source of nonindigenous species or pathogens depending upon the origin of the ship, route and time of transit, and the effectiveness of the anti-fouling paint and the overall condition of the hull. The sea chest is a repository of organisms from across the travels of the ship.

A confounding factor is that a number of other vessels will use the same port facilities and all are potential sources of invasion. Fishing fleets and pleasure craft, for example, often take very long voyages and may transport nonindigenous species to a harbor. Also, these "other" vessels exist in regulatory environments different than those of cargo ships and tankers, regulations that may be less restrictive with respect to the transport of nonindigenous species. Although not directly affecting the infection potential of any single ship, these "other" vessels can confound determination of treatment effectiveness or identification of an invasive species' source. So although there may be zero propagules in ballast water discharged at a facility, there will remain some probability of an invasion at the port. Hence there is a non-zero confidence interval in the example considered in Fig. 1.

The risks due to invasion are not the only risks to be considered in BWM. It will be important to assess the potential impacts of decontamination and the effluent upon the environment. Does disinfection for pathogens increase the risk to the environment from the treatment? The number of ships that use a port may also contribute to the trade-off. Decontamination activities that release an effluent with some residual toxicity may not pose an important risk to a facility that has a low volume, but may be important in a busier port. Some ports are very specialized. Port Valdez AK specializes in the shipping of crude oil and some oil product. Cherry Point WA is a port that currently receives crude from a limited number of sites to the refineries and bauxite for the smelter. Other facilities such as New Orleans or Seattle-Tacoma receive a variety of container ships and cargoes from across the world.

Shipboard emergencies, accidents and equipment failure should be considered in the risk analysis and decision making process. Weather conditions or shipboard emergencies may preclude the operation of shipboard treatment facilities. Operator error or equipment failure may happen on shipboard or on-shore facilities just as it does in waste-treatment facilities. In parts of the U.S. hurricanes and northeasters can damage ships and on-shore equipment. No matter the weather, accidents and equipment failure will occur and will introduce nonindigenous species to a port facility. Maximizing reliability of the BWMS should be an important part of the risk analysis process.

6. BWM in an overall management program

Large-scale establishment of species have occurred from what appear to be multiple invasions. Kolar and Lodge (2001, 2002, Kolar 2004) have demonstrated that the Great Lakes are examples in which populations of European fish have been established from multiple invasion events. European Green Crab were established in San Francisco in the late 1980s and have spread north along the west coast (Behrens and Hunt 2000). Invasions take time, often decades, are often due to multiple releases, and are difficult to control once established. A BWM strategy to decrease the rate of successful invasions should be part of an overall plan for the reduction of invasion events, monitoring, containment and eradication. Emphasis only on one aspect, the initial invasion event, is not likely to reduce the risk of successful invasions to an acceptable probability.

7. Conclusions

Decisions on approaches to ballast water management can be viewed in the framework of risk assessment. The risk assessment process should incorporate the following features.

A risk assessment for managing ballast water invasion should recognize the stochastic and non-linear, nature of the invasion process.

A clear management goal needs to be defined, and the effectiveness of the BWMS needs to be evaluated in the context of other sources of invasive species on the vessel, the treatment system, and the specific receiving habitat.

A ballast water management strategy to decrease the rate of successful invasions should be part of an overall plan for the reduction of invasion events, monitoring, containment, and eradication. Emphasis only on one aspect, the initial invasion event, is not likely to reduce the risk of invasions to an acceptable probability. Such a management system is addressed in Section 6 of this report.

2.3.3.*Glossary of Terms*

To clarify the terms used in this report, we provided the following glossary.

IMO: refers to the "International Maritime Organization." The IMO is a subsidiary body of the UN whose principal responsibility is to develop and maintain the international regulatory framework for shipping with respect to safety, environmental concerns, legal matters, technical co-operation, and maritime security. It accomplishes this,through treaties negotiated under its auspices. The Marine Environment Protection Committee (MEPC) is the principal IMO committee with responsibility for environmental issues associated with shipping. For more information: http://www.imo.org/home.asp

IMO D-2: refers to the ballast water discharge standards (expressed as concentrations of organisms per unit of volume) that are contained in Regulation D-2 of the IMO Ballast Water Convention (Table 1.1). The US has not ratified the treaty, and additional countries must ratify it before it enters into force.

10x D-2, 100x D-2, 1000x D-2 These phrases are shorthand ways of referring to concentration limits that are 10 times, 100 times, or 1000 times smaller than the concentration limits specified in IMO D-2, for one or both of the organism size classes in IMO D-2 (organisms with minimum dimension above 50 µm, or between 10 and 50 µm). It does not also mean 10 times more stringent for the D-2 indicator microorganisms.

Type approval refers to the process under which a type of equipment is tested and certified by a Flag state or its authorized representative (such as a Class society) as meeting an applicable standard specified in treaty, law or regulation. This is conducted on a sample piece of equipment which in all material respects is identical to the follow-on production units. For the IMO Ballast Water Convention, type approval testing (sometimes called "efficacy testing") is conducted under the "G8 Guidelines" described in Regulation D-3(1) of the Convention. These require both land-based and shipboard testing to verify the equipment's ability to meet the IMO D-2 standards. In the US, a generally similar type approval procedure (ETV, see below) was proposed as part of the Coast Guard's August 28, 2009 notice of proposed rulemaking.

G-9 approval, both "Basic Approval" and "Final Approval": Under Regulation D-3(2) of the IMO Ballast Water Convention, ballast water treatment systems that make use of "active substances" (biocides or other potentially harmful substances) are subject to approval by the IMO's Marine Environment Protection Committee (MEPC) with respect to active substance-related health, environmental, and safety issues. This review and approval is conducted under the "G9 Guidelines" developed by MEPC, which are available at http://www.regulations.gov/search/Regs/home.html#documentDetail?R=09000064807e890e.

"Basic Approval" requires laboratory or bench-scale testing, while "Final Approval" requires testing an actual piece of equipment. The Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP), an advisory body established by the United Nations in 1969, conducts the technical reviews and makes approval or denial recommendations to MEPC. MEPC then makes the G9 approval decisions.

Challenge conditions: This refers to the challenge water (influent) conditions specified in the IMO's G8 guidelines (http://www.regulations.gov/search/Regs/home.html#documentDetail?R=09000064807e8904), or in § 5.2 of EPA's Environmental Technology Verification (ETV) draft Generic Protocol for Verification of Ballast Water Treatment Technologies (http://standards.nsf.org/apps/group_public/download.php/7597/Draft%20ETV%20Ballast%20Water%20Prot-v4%202.pdf).

ETV refers to the U.S. EPA *Generic Protocol for the Verification of Ballast Water Treatment Technology*, Version 5.1. 2010. Report number EPA/600/R-10/146, U.S. EPA Environmental Technology Verification Program, Washington, DC; report authors were E. Lemieux, J. Grant, T. Wier, and L. Drake.

3. Statistics and interpretation

3.1 Introduction

The goal of this section is to present key aspects of statistical interpretations that are most relevant to the operational conditions in which ballast water management systems (BWMSs) are tested for type approval. These conditions include the need to sample large volumes of water, particularly for the size class of organisms ≥ 50 μm in minimum dimension (nominally zooplankton) of the IMO/P-I performance standard, and to apply statistical methods that can quantitatively assess the confidence of test results obtained from counts of low numbers of organisms. Note that these discussions pertain to land-based and shipboard testing to determine conformity to a given performance standard. Although the same statistical theory would apply to compliance testing by port state control officers for compliance or gross non-compliance (e.g., exceedance of a standard by orders of magnitude), compliance testing is not discussed here.

Credible testing to determine conformity to any standard for effectiveness of BWMSs requires the following process. First, relatively large volumes of water must be collected and filtered in some way to concentrate organisms into a manageable volume. The volume of ballast water carried by commercial ships ranges from a few thousand m3 to greater than 100,000 m3. The volume of water that must be sampled following treatment is a small fraction relative to the total volume in a ballast tank or ship but, nonetheless, a large volume must be filtered to determine the number of live zooplankton-sized organisms. This size class has the lowest concentration threshold – organisms per m3 vs. organisms per mL in the other two size classes – and represents the most challenging size class in terms of sampling to achieve statistical rigor. Hence, many of the examples in the following discussion will focus on zooplankton-sized organisms. The required sample volumes for these organisms, which are determined by a number of factors, are in the range of five to tens of m3; the latter approximates the volume of a city bus. In all size classes, subsamples of the concentrated volume are analyzed for viable (living) organisms, as all present standards are based on the number of organisms surviving the treatment method. Once these counts are in hand, how reliably they portray conditions in the ballast water discharge must be determined. To accomplish this task, the live organism counts are analyzed using statistical methods to assess the uncertainty associated with the counts.

Assessing uncertainty in test results requires accounting for the spatial nature of the distribution of zooplankton in the sampled volume of water. Different probability distributions apply depending upon whether zooplankton are randomly distributed throughout a sample or are aggregated. Therefore, this section illustrates how the use of appropriate probability distributions can characterize the level of reliability in taking the important inferential step from observing actual zooplankton counts to determining whether a stated standard has been met.

3.2 Ascertaining in a Rigorous Manner Whether Ballast Water Standards are Met — The Statistics of Sampling

With regard to detecting whether or not treated ballast water meets a stated standard in terms of the density of viable organisms of any size class in a ship's ballast water, "zero detectable discharge" initially seems a desirable standard to achieve (see also the response to charge question 1c). However, without a well-defined, rigorous protocol based upon probability sampling, any standard, no matter how stringent, will be difficult to assess and defend. Furthermore, it will be impossible to compare the effectiveness of different BWMSs without rigorous protocols. In order to outline what a sampling scheme might entail, and what sorts of information it would yield, it is necessary to investigate the probabilistic characteristics of plankton in ballast water.

In considering concentrations that approach the IMO/P-I performance standard (or a more stringent standard), organisms can have one of two spatial characteristics: they can be randomly dispersed or clumped (aggregated) (see Lee et al., 2010). Because any sampling protocol is a function of the organisms' spatial distribution, it is critical to understand the distribution in the tank and discharge pipe and then sample accordingly. For randomly distributed organisms that are not abundant, the Poisson distribution can be used to estimate probabilities and conduct statistical power analyses (the probability that the sampling will find a vessel in or out of compliance when that is the case). Other hypervariable discrete alternatives to the Poisson distribution are available, such as the Poisson Long Normal and Poisson Inverse Gaussian distributions. Because the approach taken to date by statisticians examining samples of treated ballast water has been to use the Poisson distribution, it will be the focus here. For concentrations that are spatially aggregated, the negative binomial distribution is appropriate as the underlying statistical model. Here, we first consider the Poisson distribution and its relevance to ballast water sampling.

3.2.1 The Poisson distribution

Theoretical considerations

The Poisson distribution has the property that its variance is equal to its mean, resulting in an increase in variability at higher densities. Since the Poisson distribution pools the data to improve measurement precision, sample replication is unnecessary if one subsample is continuously taken on a time-averaged basis and is therefore representative of the sample (as is required in the EPA Environmental Technology Verification (ETV) Generic Protocol for the Verification of Ballast Water Treatment Technology; U.S. EPA 2010). Assuming a given concentration in this exercise, one can calculate the volume needed in order to guarantee a stated probability of finding at least a single plankter in a sample of that volume. Note that an underlying assumption is that organisms are randomly distributed – but see the section below on spatially aggregated populations.

A major challenge of sampling at low organism concentrations is that many samples will detect zero live organisms because the few live organisms present are missed. To improve the probability of detecting them, impractically large volumes must be sampled and excellent detection techniques must be used to enable detection (Fig. 3.1).

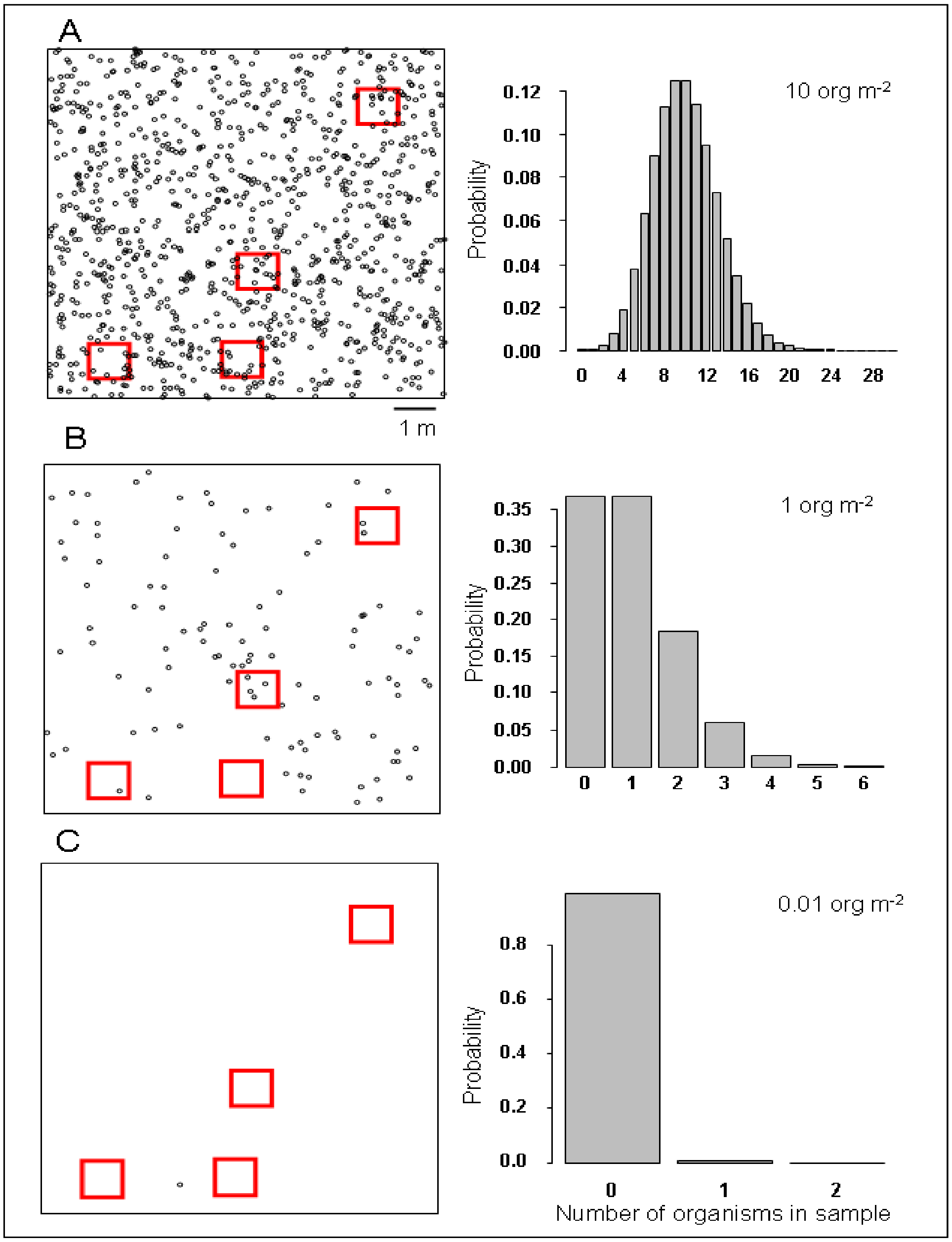


Figure 3.1
. Illustration of the need to sample very large volumes to detect low concentrations of organisms present, assuming random distribution: Probability distributions for random samples of 1 m^2 for a randomly distributed population with 10 (A), 1 (B), or 0.01 (C) organisms m^{-2}. Red squares represent random samples. The data are displayed in terms of area with units of m^2, but the probabilities are the same for volumes. Plots on the right indicate the probability that a 1 m^2 sample will contain a given number of organisms. At low concentrations, the concentration of organisms is likely to be estimated as 0 organisms m^{-2}, unless very large volumes are sampled. From Lee et al. (2010), with permission.

Consider the following examples from Lee et al. (2010): from the Poisson distribution, if 1 m^3 of ballast water was sampled from a ballast water discharge that had a concentration of 10 zooplankton-sized organisms m^{-3}, about 95% of the samples would contain 4-17 organisms m^{-3}. As the concentration of organisms decreases, the frequency distribution becomes increasingly skewed, and there is a high probability of obtaining a sample with zero organisms. Thus, if the sample concentration is 1 organism m^{-3}, the probability of a 1 m^3 sample containing zero organisms is 36.8%. If the sample concentration is only 0.01 organism m^{-3}, or 1 organism in 100 cubic meters of ballast water, the probability of obtaining a sample with zero organisms is ~99%. Moreover,

> "If a small volume is used to evaluate whether the discharge meets a standard, the sample may contain zero detectable organisms, but the true concentration of organisms may be quite high….For example, even with a relatively high concentration of 100 organisms m^{-3}, only about 10% of 1-L samples will contain one or more organisms. Furthermore, even if zero organisms are detected in a 1-L sample, the upper possible concentration, based on a 95% confidence interval, is about 3,000 organisms m^{-3}….The general point is that more organisms may be released in ballast discharge using a stringent standard paired with a poor sampling protocol than a more lenient standard paired with a stringent sampling protocol" (Lee et al. 2010, p.72).

The ETV Protocol stipulates that biological samples (for all three size classes) should be continuously acquired on a time-averaged basis from a sampling port positioned in fully turbulent flow (U.S. EPA, 2010), and are thus representative of the entire volume to be sampled. It has been argued that organism abundance in BWMS testing can be statistically represented by the Poisson distribution and, therefore, the cumulative or total count is the key test statistic (Lemieux et al., 2008). A Chi-square distribution can also be used to approximate confidence intervals (CIs). However, experimental validation must be obtained to ensure that testing organizations can accomplish detection of live organisms with quantified uncertainty (see Section 5. II. C. B on viability).

The available methodologies for testing compliance with the IMO standards for zooplankton-sized organisms and organisms ≥ 50 μm are at or near the analytic detection limits. The following example from the ETV Protocol (U.S. EPA, 2010) illustrates the problem: For the desired minimum precision in quantifying zooplankton-sized organisms, consider an example where the upper bound of the Chi-square statistic should not exceed twice the observed mean (corresponding to a coefficient of variation of 40%, which is relatively high). Then, ***if 6 or fewer*** live organisms are counted, the upper bound of the 95% CI for the volume sampled does not exceed the IMO/P-I performance standard for zooplankton-sized organisms (i.e., the ≥ 50 μm size class, < 10 viable individuals m^{-3}):

- Coefficient of variation (CV) = standard deviation (SD) divided by the mean (M).
- For the Poisson distribution, the variance (V) = SD^2 = M.
- Substituting the critical value of the mean, 6: CV = $6^{1/2}/6 \approx 40\%$.

The volume needed to find and quantify 6 live organisms per m^3 depends on the whole-water sample volume, the concentration factor, and the number of subsamples examined. Very large sample volumes (10s of m^3) are required to quantify viable zooplankton-sized organisms (assuming 20 mL of the concentrated sample is analyzed), and each sample must be concentrated down to a manageable volume (concentrating 3 m^3 to 1 L would yield a concentration factor of 3,000). Based on the Poisson distribution for a 95% CI from the Chi-square distribution, 30 m^3 (30,000 L) must be sampled in order to find and count <10 organisms m^{-3} with the desired level of precision. The total sample volume can be reduced if the concentration factor is increased (and the same subsample volume analyzed), if the CI is also lowered (e.g., from 95% to 90%) or the subsample volume analyzed is increased (e.g., from 20 mL to 40 mL). Notably, as the concentration factor increases, the likelihood of losing organisms or inadvertently killing them in the sample processing steps increases (see Section 6.2.4 (A) below).

The ETV Protocol provides examples of the sample size needed to provide the level of precision needed to achieve a 95% upper confidence limit that is no more than twice the observed mean and does not exceed the targeted concentration (Tables 2.1 and 2.2; U.S. EPA, 2010). If the volume of subsample that is analyzed is increased, then validation experiments should be conducted to ensure that counting accuracy is acceptably high. The problem is exacerbated for zooplankton-sized organisms (≥ 50 µm size class) because they are sparse compared to organisms in the next smaller size class (here, referred to as "protist-sized" organisms). The Poisson distribution assumption still applies to this smaller size class, and the ETV Protocol provides examples with a more stringent level of precision than is used for the larger size class (Table 2.2; U.S. EPA 2010). Nonetheless, it should be noted that it is time consuming to concentrate whole seawater by filtering it through mesh having a hypotenuse of 10 µm; the Phase I standard (10 protist-sized organisms mL^{-1}), either analyzing several mL of subsamples from a time-integrated sample or requiring 3 to 6 L to be concentrated to 1 L, are the practical limits currently achievable by testing facilities in the U.S. (e.g., Maritime Environmental Resource Center, 2009, 2010a, 2010b; Great Ships Initiative, 2010). Additionally, determining viability of protist-sized organisms remains problematic because many organisms do not move during time scales over which they are observed (as do many zooplankton; see Section 6.2.2 for a discussion of viability determination).

Table 3.1. Sample volume of treated ballast water required relative to treatment standards for organisms ≥ 50 µm (nominally zooplankton), assuming that the desired level of precision of the estimated density is set at the 95% confidence interval of the Poisson distribution (= twice the observed mean and not greater than the standard limit). These are the required whole-water sample volumes that must be concentrated to 1 L as a function of N, the number of 20 1-mL subsamples analyzed. Reprinted with permission from U.S. EPA (2010).

Concentration (i.e., performance standard) (individuals m^{-3})	N = 1	N = 3	N = 5
	Sample Volume Required (m^3)		
0.01	60,000	20,000	12,000
0.1	6,000	2,000	1,200
1	600	200	120
10	6	20	12

Table 3.2. Sample volume of treated ballast water required relative to performance standards for organisms ≥ 10 µm and < 50 µm (nominally protists), assuming that the desired level of precision is set at a CV of < 10%. These are the required whole-water sample volumes that must be concentrated to 1 L as a function of N, the number of 1-mL subsamples analyzed. Reprinted with permission from U.S. EPA (2010).

N =	**2**	**3**	**4**
Concentration (i.e., performance standard) (individuals mL^{-1})	Sample Volume Required (L)		
0.01	6,000	4,000	3,000
0.1	600	400	300
1	60	40	30
10	6	4	3

It is expected the statistics governing the smallest size classes, the < 10 µm protists proposed below and the indicator and pathogenic bacteria (Escherichia coli, Enterococci, and Vibrio cholerae), will be similar to the two size classes discussed here. That is, treated samples meeting or approaching the D-2/Phase-one performance standard will be sparse populations in well-mixed samples, thus the Poisson distribution would be applicable.

Laboratory experiements with protist cultures support use of the Poisson distribution

A workshop recently was held to evaluate four methods for enumerating living protists in treated ballast water (Nelson et al. 2009, Steinberg et al., submitted). Live and dead cells were counted using flow cytometry, an enhanced flow-through system with imaging capacity (FlowCAM®, Fluid Imaging Technologies, Yarmouth, ME), direct counts of samples collected on membrane filters, and direct counts using a Sedgewick Rafter counting chamber. All techniques used fluorescent stains to differentiate between live and dead cells. Counting methods were tested with several ratios and densities of live and dead Tetraselmis sp., a small phytoflagellate. In these trials, comparisons were conducted under ideal conditions with no debris or particulate matter and with a single target species.

Data were evaluated to determine whether they conformed to a Poisson distribution if the variance was equal to the mean. At low concentrations of living cells (approximately 10 mL^{-1} to 100 mL^{-1}), there was no evidence to reject the Poisson hypothesis (Nelson et al., 2009).

Accuracy and precision in sparse samples following a Poisson distribution

A series of laboratory experiments was conducted to assess the accuracy and precision of enumerating zooplankton- and protist-sized organisms at a variety of densities (Lemieux et al. 2008). Inert, 10-µm standardized microbeads at densities of 1, 5, 10, 50, 100, 500, and 1,000 microbeads per mL of artificial seawater represented protist-sized organisms, and 150-µm microbeads at 10, 30, and 60 microbeads per 500 mL represented zooplankton-sized organisms. Such inert, standardized polymer microbeads were used rather than organisms to eliminate any potential bias, and artificial – rather than natural – seawater was used to avoid inclusion of various organic particles (e.g., detritus) that could interact with the microbeads and confound interpretations. Here, microbeads served as proxies, and it is acknowledged they are an imperfect representation of living organisms (e.g., microbeads do not exhibit the swimming behavior of many planktonic organisms; living organisms can cling to nets or filters and can also be squeezed through a net more readily than microbeads). Nonetheless, if the items of interest in a sparse concentration – be they microbeads or living organisms in treated ballast water – are well mixed, the Poisson distribution should be applicable.

At each microbead density, the percent difference of the observed mean from the expected mean indicated counting accuracy, and the CV indicated the level of precision. In this study, benchmarks for acceptable accuracy and precision were established at a percent difference of 10% and a CV of 0.2 (20%), respectively. For the "protist" microbeads, the 50 - 1,000 mL^{-1} concentrations were not significantly different, with acceptable accuracy and precision below the 10% and 20% benchmarks, respectively. Unfortunately, however, analysis of the "zooplankton" microbead populations at all densities showed poor precision, with CVs well above 20%, and only counts at the highest density showed a CV < 100%. All densities of "zooplankton" microbeads showed acceptable accuracy (i.e., a percent difference < 10%) after sufficient aliquots were examined to result in a stable mean.

From this work, Lemieux et al. (2010) recommended that samples for analysis of the protist-size class (≥ 10 µm and < 50 µm) should be concentrated by at least a factor of five, and that at least four replicate chambers (e.g., four Sedgewick Rafter slides) should be counted for acceptable accuracy and precision, including evaluation of at least 10 random rows (from a total of 20) of the counting chamber. Importantly, for the zooplankton size class (≥ 50 µm) size class, Lemieux et al. (2008) deemed the draft ETV protocol (Battelle, 2003) recommendations for sample sizes as inadequate to achieve acceptable precision. The data from these microbead experiments indicated, instead, that this size class requires a sample size of greater than 6 m^3, concentrated to 0.5 L (i.e., by a factor of 12,000), and analysis of at least 450 1-mL aliquots, as CVs at the highest volumes were > 20%; as higher concentration factors were likely unrealistic, and it was suggested that larger sample sizes and improved analytical methods should be considered. Lemieux et al. (2008) also noted that these laboratory trials represented a "best case" situation because the study was conducted under simplified, "ideal" conditions rather than with natural organism assemblages in natural seawater.

When concentrations are close to the performance standard, a single sample may require too large a volume of water to be logistically feasible. In that case, complete, continuous time-integrated sampling (with the entire volume analyzed) and combining samples across multiple trials can improve resolution while maintaining statistical validity. To that end, Miller et al. (2010) applied statistical modeling (based on the Poisson distribution) to a range of sample volumes and plankton concentrations. They calculated the statistical power of various sample volume and zooplankton concentration combinations to differentiate various zooplankton concentrations from the proposed standard of < 10 m^{-3}. Their study involved a two-stage sampling approach. Stage I checked compliance based on a single sample, which was expected to be effective when the degree of noncompliance was large. Stage 2 combined several samples to improve discrimination (1) when concentrations are close to the performance standard, or (2) when a large volume single-trial sample would be logistically problematic, or both. The Stage 2 approach took advantage of the fact that the sum of several Poisson random variables is still a Poisson distribution, and is thus called the "summed Poisson method". Stage 2 also compared the summed Poisson approach to power calculations using standard t-tests, the nonparametric Wilcoxon Signed Rank test (WSRT), and a binomial test, all well-known statistical techniques. The summed Poisson approach had more statistical power relative to the other three statistical methods. Not surprisingly, as noncompliant concentrations approached the performance standard, sampling effort required to detect differences in concentration increased.

The major finding from Miller et al. (2010) is that three trials of time-integrated sampling of 7 m^3 (and analyzing the entire concentrated sample from the 21 m^3) from a ship's BW discharge can theoretically result in 80% or higher probability of detecting noncompliant discharge concentrations of 12 vs. 10 live organisms m^{-3}. Thus, pooling volumes from separate trials will allow lower concentrations to be differentiated from the performance standard, although the practicability and economic costs of doing so have not been evaluated. Moreover, the practical limits of increased statistical sample sizes may already tax the capabilities of well-engineered ballast water test facilities. Attaining a standard 10x more stringent than the IMO D-2/Phase I standard would require that 10x more sample volume would be analyzed (three trials of 70 m^3), which is impracticable at this point – test facilities in the U.S. typically analyze ~5 m^3 of water per test (e.g., Maritime Environmental Resource Center, 2009, 2010a, 2010b; Great Ships Initiative, 2010)

Additional challenges of sampling large volumes

As outlined in Lee et al. (2010), the detection of viable organisms (particularly zooplankton-sized organisms) at very low concentrations, required to assess performance and compliance, is a major practical and statistical challenge, partly because of the inherent stochasticity of sampling. Due to random chance, the number of organisms in multiple samples taken from the same population will vary. In addition, very large volumes of water must be sampled in order to accurately estimate the organism densities. Three other considerations are presented as follows.

First, statistical approaches in assessing treatment performance generally rest upon the premise that the samples realistically represent the actual concentrations of organisms discharged, which, in turn, is based on two assumptions: random distribution of organisms in both ballast tanks and discharge water, and no human or equipment error that would lead to failure to detect organisms in a sampled volume. Neither assumption will be true all of the time. Human and equipment errors will occur, and organisms are typically "patchy" or non-random in the water column of a tank or the stream of a large-volume discharge (Murphy et al. 2002, U.S. EPA 2010). The assumptions are made for practical reasons; if appropriate quality control and assurance were used in collecting the data, then human error and equipment malfunction would have been accounted for. Regarding the second assumption, data are usually lacking to estimate aggregation in ballast water.

Second, the logistics of managing large sampling containers, sample transport costs (since samples usually are not processed aboard ship), analytical supplies, and personnel time would make it impractical to process all of the volume of even one 100 m^3 sample, much less multiple samples, especially in Type Approval of BWMSs, when multiple, successful tests are required.

Lee et al. (2010) calculated the probability of finding one or more organisms in a sample as $1\text{-}e^{cv}$ (1 minus the probability of finding no organisms) for a series of organism concentrations and sample volumes, where e ≡ the natural log, c ≡ the true concentration of organisms, and v ≡ the sample volume (Table 2.3). They used the following assumptions:

- Performance standards are for the concentration of organisms in the ballast discharge (rather than the maximum number of organisms), so that the purpose of sampling is to estimate the “true” concentration of organisms in the discharge, referred to as average-based sampling;

- The organisms are randomly distributed and therefore amenable to modeling with the Poisson distribution, as above;

- All organisms are counted, with no human or instrumentation errors, so that any variation among samples for a given population (species) is from the natural stochasticity of sampling;

- The sample volume is calculated from the total volume of ballast water filtered (concentrated) and the filtrate volume that is subsampled. For example, following Lemieux et al. (2008): 100 m^3 of ballast water is filtered through a net to retain the zooplankton-sized organisms; the organisms are rinsed from the net, collected, and diluted up to 1 L of water to give a concentration factor of 100,000:1. The organisms from 20 1-mL subsamples are counted: Total sample volume = 20 mL subsamples/1000 mL concentrated sample x 100 m^3 ballast water filtered = 2 m^3.

As Table 3.3 illustrates, 100 L of ballast must be sampled to have a >99% probability of detecting at least 1 zooplankton-sized organism when the true concentration is 100 organisms per m^3. When small sample volumes are collected, the probability of detecting an organism is low even at relatively high organism concentrations; for example, organisms will be detected in fewer than 10% of subsamples if a 1-L sample is taken and the “true” concentration is 100 organisms m^{-3}. This analysis also illustrates that when no organisms are detected from a

Table 3.3. Probability of detecting ≥ 1 zooplankton-sized organism for sample volumes (100 mL to 300 m^3) and ballast water concentrations (0 to 100 organisms m^{-3}). Gray boxes indicate probabilities of detection ≥ 0.95. Reprinted with permission from Lee et al. (2010).

	True concentration (organisms per m^3)						
Sample volume, m^3	**0**	**0.001**	**0.01**	**0.1**	**1**	**10**	**100**
0.0001 (100 mL)	0	<0.001	<0.001	<0.001	<0.001	0.001	0.01
0.001 (1 L)	0	<0.001	<0.001	<0.001	0.001	0.01	0.095
0.01 (10 L)	0	<0.001	<0.001	0.001	0.01	0.095	0.632
0.1 (100 L)	0	<0.001	0.001	0.01	0.095	0.632	>0.99
1	0	0.001	0.01	0.095	0.632	>0.99	>0.99
5	0	0.005	0.049	0.393	>0.99	>0.99	>0.99
10	0	0.010	0.095	0.632	>0.99	>0.99	>0.99
25	0	0.025	0.221	0.918	>0.99	>0.99	>0.99
50	0	0.049	0.393	>0.99	>0.99	>0.99	>0.99
100	0	0.095	0.632	>0.99	>0.99	>0.99	>0.99
300	0	0.259	0.950	>0.99	>0.99	>0.99	>0.99

relatively small sample, the true concentration in the ballast tank may be large – it depends on the sample volume collected.

Lee et al. (2010) then estimated the upper possible concentration (UPC, upper 95% CI) of organisms actually present in ballast water from the number of zooplankton-sized organisms in a sample volume (ranging from 100 mL to 100 m^3) based on the Poisson distribution. As Table 3.4 shows, 0 organisms detected in 1 m^3 of sample could correspond to a true concentration of organisms in the ballast tank of up to ~3.7 organisms m^{-3}. The error is much larger for a small sample volume of 1 L; 0 organisms detected could correspond to a true concentration of ~3,700 organisms m^{-3}.

Table 3.4. Upper possible concentration (UPC) of zooplankton-sized organisms based on one and two tailed 95% exact confidence intervals when zero organisms are detected in a range of sample volumes. Reprinted with permission from Lee et al. (2010).

	Upper possible concentration, org m^{-3}	
Sample volume, m^3	**one-tailed**	**two-tailed**
0.0001 m^3 (100 mL)	29,960	36,890
0.001 m^3 (1 L)	2,996	3,689
0.01 m^3 (10 L)	299.6	368.9
0.1 m^3 (100 L)	29.96	36.89
0.5 m^3 (500 L)	5.992	7.378
1 m^3	2.996	3.689
10 m^3	0.300	0.369
100 m^3	0.030	0.037

Third, in the above analyses, the true concentrations of zooplankton-sized organisms are known. The goal in sampling unknown concentrations of organisms in ballast water is to accurately assess whether a given ballast water treatment system produces treated water with true organism concentrations that pass or fail a set performance standard. Inherent stochasticity of sampling may result in an indeterminate category, as well, and the probability of obtaining an indeterminate evaluation increases with decreasing sample volume and increasing stringency of the ballast water standard (Figure 3.2). Based on this analysis, it would be necessary to sample ~0.4 m^3 of ballast water to determine whether the IMO standard of < 10 zooplankton-sized organisms m^{-3} was met if less than approximately 10 organisms were observed in the sample (Figure 3.2 B).

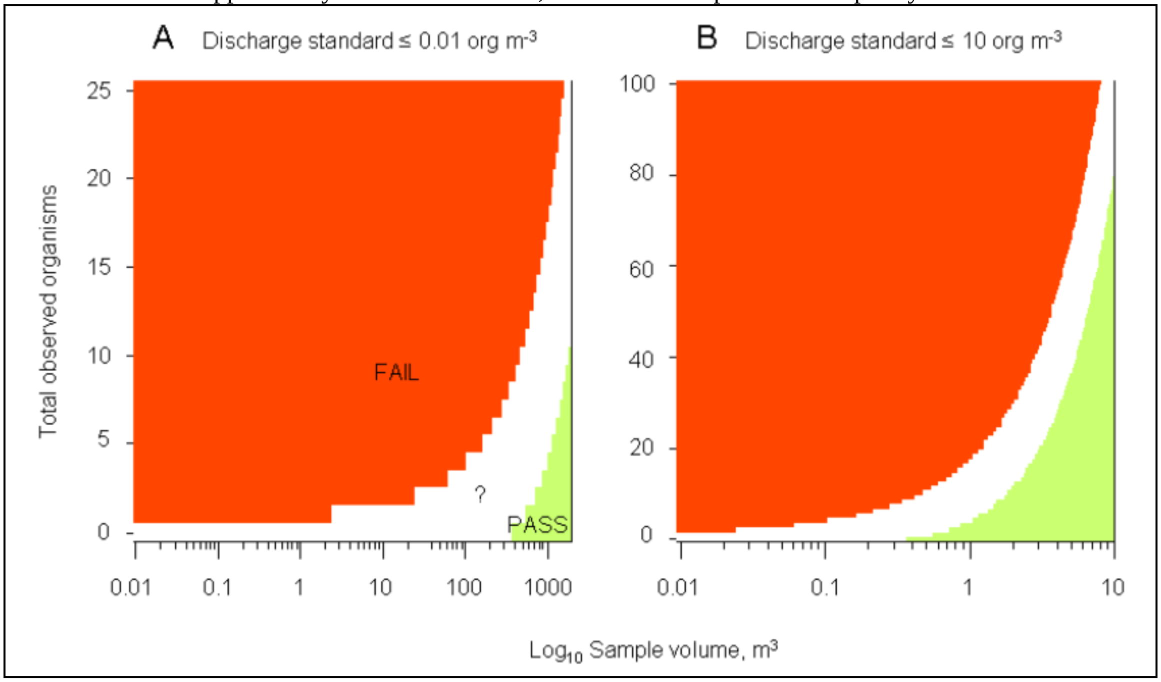


Figure 3.2 Determining whether ballast water discharge exceeds or meets a performance standard of < 0.01 (A) and <10 (B) organisms m-3 (note: axes have different scales). Red regions indicate total organism counts that exceed the standard. Green regions indicate total organism counts that meet the standard. White regions indicate indeterminate results; counts in this region do not pass or fail inspection based on two-tailed 95% confidence intervals. Reprinted with permission from Lee et al. (2010).

3.2.2 Spatially Aggregated Populations – Negative Binomial Distributions

If organisms are aggregated (i.e., in clumped or contagious populations) rather than randomly distributed in the ballast tank, a different statistical approach is required. For aggregated populations, the variance exceeds the mean (negative binomial distribution, σ2 > μ); thus, as the variance increases, the number of organisms in a random sample is increasingly unpredictable. Because it is more difficult to accurately estimate the true concentration, more intensive sampling is required. Lee et al. (2010) recommend use of the negative binomial distribution to model aggregated populations. This distribution can be used to predict the probability of finding a certain number of organisms in a sample. It is defined by the mean (μ) and the dispersion or size parameter (θ = μ2/(σ2 - μ)); the smaller the dispersion parameter, the more aggregated the population.

The problem of having to sample multiple subsamples from large volumes to accurately assess low densities of organisms is compounded by aggregated distributions (Figure 3.3). In the comparison given in Lee et al. (2010), for a randomly distributed population with a true concentration of 1 zooplankton-sized organism m-3, ~37% of the subsamples from a 1 m3 sample of treated ballast water would contain zero zooplankton-sized organisms. For an aggregated population with a dispersion parameter of 0.1, however, ~79% of the subsamples would contain zero organisms (Figure 3.3). The relationship between the probability of finding zero organisms in a sample and the amount of aggregation is also illustrated (Fig. 3.4) for the concentration of 1 organism m-3. As variance σ2 increases, the dispersion parameter θ decreases, indicating more aggregation, with increasing probability of finding no organisms in a sample. With more aggregation, the probability of samples containing large numbers of organisms relative to the true concentration also increases. Thus, large numbers of subsamples from large sample volumes must be taken to account for aggregated populations; otherwise, there will be a high probability that the concentration estimates from sample analyses will be either much lower or much higher than the true concentration.

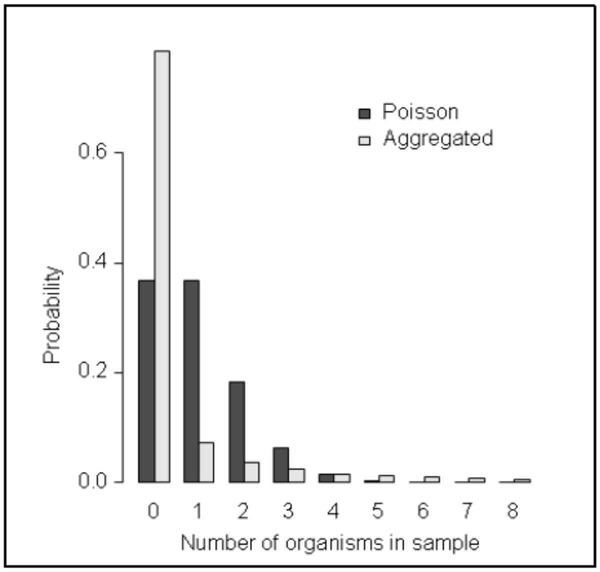


Figure 3.3. Comparison of sample probabilities from a randomly distributed population (Poisson distribution) vs. an aggregated population with a dispersion parameter of 0.1 (negative binomial distribution) for a sample volume of 1 m^3 and concentration of 1 organism m^{-3}. For low organism numbers (3 or fewer m^{-3}), the probability that a sample will contain zero organisms tends to be much greater for the aggregated population. Reprinted with permission from Lee et al. (2010).

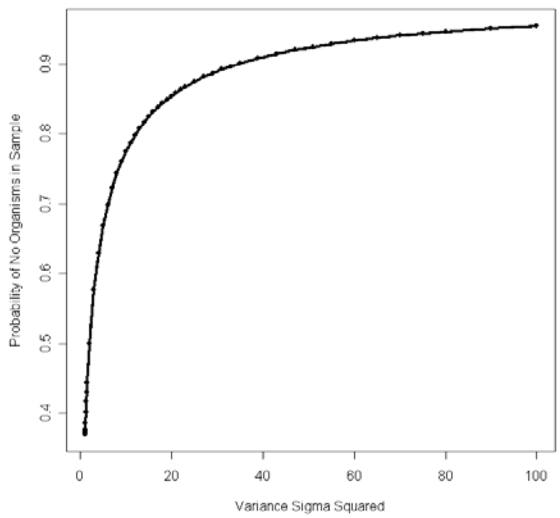


Figure 3.4. The probability of finding zero organisms in a sample volume of 1 m^3 and concentration of $\mu = 1$ organism m^{-3}. The probability of 0 organisms = $(1 + \theta)^{-\theta}$, where dispersion parameter $\theta = 1/(\sigma^2 - 1)$. When $\sigma^2 = 1.0$, organisms are randomly distributed, at which the probability of 0 organisms in the sample = 0.37 (Poisson distribution) (Elliott 1971).

Determination of whether a population is aggregated is complicated, since the scale of the aggregation pattern in comparison to the size of the sampling unit controls estimates of aggregation (Fig. 3.4). If organisms form clumps that are randomly distributed, the population may be highly aggregated, but in a small sample volume containing 0 or 1 organisms, the population will appear randomly distributed or only slightly aggregated. With increasing sample volume, the variance in the number of organisms increases in comparison to the mean, and maximum variance is encountered when the sample volume is equal to the volume of a single cluster of organisms (Elliott 1971). For larger sample volumes, a sample unit will include several clusters, so the variance decreases in comparison to the mean and the observations will approach a Poisson distribution. Lee et al. (2010) recommend the Taylor power law (Taylor 1961) as an alternative to the negative binomial, because it can accommodate a wider range of aggregated distributions than the negative binomial.

Overall, the possibility for and degree of aggregation represent major challenges in sampling sufficiently large volumes of ballast water to determine whether a given BWMS passes or fails to meet standards more stringent than the present IMO guidelines, even if the true concentrations of organisms are 10- to 1,000-fold higher than the performance standard. This remains a major problem in quantifying many protist-sized organisms, but becomes less of a problem with very small organisms such as bacteria, which have a tendency to clump but are effectively counted as colonies and not individuals. Furthermore, in Lemieux et al. (2008), data from protist-sized microbeads at various concentrations were analyzed and concentrations of 100 mL^{-1} and lower were found to adhere to a Poisson distribution. The flasks of microbeads were well mixed, as would be samples of ballast water collected from the sample ports and collected to be representative of the entire volume sampled (e.g., over the entire discharge operation of the tank). Likewise, monocultures of protists in low densities (~10 mL^{-1} – 30 mL^{-1}) adhered to a). Likewise, monocultures of protists in low densities (~10 mL^{-1} – 30 mL^{-1}) adhered to a Poisson distribution (Nelson et al., 2009). Those data lend support to using the Poisson distribution to analyzed ballast water samples.

3.3 Interactive Effects

A final consideration regarding statistical analysis concern the potential for covariance, or interactive effects among environmental conditions – for example, a treatment system may perform well under high-temperature or high-biomass conditions, but not both (Ruiz et al., 2006). To address this problem, covariate measurements should be addressed in experiments, and treatment evaluations should consider the potential for interactions and target tests of especially challenging combinations.

3.4 Certainty of Results

It is necessary to keep in mind that, as with all statements that are based upon statistical sampling, there is always a stated non-zero error probability (e.g., 0.1%, 1%, 5%) associated with a particular statistical conclusion used to meet a regulatory standard. Thus, one can never claim to be 100% certain that, for example, the concentrations of live zooplankton-sized organisms is below (for example) 10 m-3. Available methodologies to test IMO D-2/Phase 1 compliance are presently at or near analytic detection limits for the two largest organism size classes. While the IMO D-2/Phase 1 performance standards are measureable at present based on land-based and shipboard testing approaches, new or improved methodologies will be required in order to increase detection limits. Due to the logistics of collecting, reducing, and counting organisms in all size classes within the volumes of water required to detect achievement of a standard 1000x more stringent than the IMO D-2/Phase 1 performance standard, measuring to a 1000x more stringent standard is impracticable. Detecting achievement of a standard 10x more stringent may be possible, but it seems unlikely for the reasons mentioned above that detecting achievement of a 100x more stringent standard is possible.

3.5 Conclusions

- Rigorous statistical sampling protocols (including consideration of the spatial distribution of plankton in ballast water) and subsequent statistical analysis are required in order to assess whether a BWMS meets desired performance standards.

- Detecting organisms in low abundance is a difficult problem, requiring very large volumes of water to be sampled, especially for the zooplankton–sized organisms (≥ 50 µm).

- The sample volumes that must be concentrated are a function of the targeted concentration, the performance standard, and the desired level of confidence (e.g., 95%, which is used most often in ecological investigations).

- The Poisson distribution is recommended as the model for statistical analysis of treated water samples.

- Available methodologies to test IMO/P-I compliance are presently at or near analytic detection limits for the two largest organism size classes. New or improved methodologies will be required to increase detection limits.

- The IMO/P-I performance standards are measureable at present based on land-based and shipboard testing approaches. Due to the logistics of collecting, reducing, and counting organisms in all size classes within the volumes of water required to achieve a standard 1000x more stringent than the IMO/P-I performance standard, measuring adherence to a 1000x more stringent standard is impracticable. Measuring adherence to a standard 10x more stringent may be possible, but it seems unlikely – for the reasons mentioned above – that a 100x more stringent standard can be measured.

- Statistical conclusions at a stated confidence level always have an associated error probability; thus, "100% certainty" is not statistically possible.

4 RESPONSE TO CHARGE QUESTIONS 1 AND 2: PERFORMANCE OF SHIPBORD SYSTEMS WITH AVAILABLE EFFLUENT TESTING DATA

4.1 Charge from EPA

This section responds to Charge Questions 1 and 2 which asked the Panel to assess the documented performance of existing BWMSs, in terms of quality of discharged ballast water, and to assess the likely future performance of BWMSs based on their design and treatment processes.

4.2 Assessment methods

The Panel Chair selected a subgroup of the Panel to lead the assessment of BWMS technologies. For this assessment, the subgroup considered only the information compiled by EPA through solicitation of various Administrations that have granted Type Approval certifications, direct communication with developers and manufacturers of BWMSs, and searches for publically available sources (such as journal or conference publications and third-party reports provided through the internet). This information is listed in Appendix 2; it included data packages, reports, publications, certification documents, and other available information on the performance of BWMSs.

Three subgroup members were then selected to independently examine in detail all data packages, with the two other members providing review oversight and quality control. The type, amount, and quality of the amount of material in the data packages varied -- some contained only a Type Approval certificate, while others included land-based and shipboard testing methods and data, documentation of G9 approval, a type approval certificate, and press releases describing the sale of systems for use on commercial vessels. The Panel notes that BWMSs are still evolving with an ever-growing number of manufacturers developing systems. Thus, this analysis represents a snapshot in time. No new data or information was considered beyond packages submitted to the SAB by December 1, 2010

4.3 Assessing the reliabilityof existing data

The three primary reviewers then independently scored each package as having ‘reliable’ or ‘unreliable’ data. At a minimum, the data package had to include methods and results from land-based or shipboard testing to earn a ‘reliable’ rating. A BWMS holding a certificate of type approval without supporting testing data was scored as having ‘unreliable’ data, because it was impossible to determine the validity of the testing procedures and, therefore, the validity of the data. If a BWMS’s data package included one or more test reports, the data package was examined according to the following criteria:

- The operational type of system (e.g., deoxygenation + cavitation) was determined to be generally appropriate for shipboard use (e.g., can it meet required flow capacities, size, power requirements, etc.).

- The technical literature supported the fundamental use of the technologies used (e.g., is it well documented that using the approach will safely and effectively remove, kill, or inactivate aquatic organisms).
- Laboratory testing was conducted with 'reasonable and appropriate methods' (i.e., methods commonly used in aquatic studies or alternative methods that appear rigorous and equivalent to a standard, common approach).
- Land-based testing was conducted with reasonable and appropriate methods; sample number and size were appropriate; sample collection and handling was appropriate and documented; analytical facilities were adequate; IMO or ETV (v. 5.0) challenge conditions were met; if necessary, toxicological studies were conducted and demonstrated environmental safety; a QA/QC policy was in place and followed; and ultimately, land-based testing produced credible results.
- Shipboard testing was conducted with the same considerations as land-based testing (described above) and produced credible results.
- If an active substance was included, the BWMS had credible toxicity and chemistry data and G9 Basic approval or G9 Final Approval (which requires Basic approval).
- The BWMS had Type Approval certification.
- The BWMS was in operational use (i.e., not used only during shipboard Type Approval testing) on one or more active vessels. A BWMS not yet having operational systems onboard vessels was not automatically categorized as having 'unreliable' data, but this information was useful.

It is important to note that if the data packages were deemed 'reliable', it was assumed that all protocols and methods were followed exactly as described. For data packages that included clear QA/QC procedures, there was a higher level of certainty that this was the case. In the absence of QA/QC documentation, which was the case for most data packages, the level of rigor in following the protocols and methods described was unknowable. &&&&&

4.4 Assessing the abilityof BWMS to meet discharge standards

For BWMSs with reliable data, the system's ability to meet four discharge standards—IMO D-2/USCG Phase I (P-I) and 10x, 100x, 1000x more stringent than IMO D-2/USCG P-I—was determined, again independently,by the three primary reviewers. The following scores and interpretations were assigned:

A -- demonstrated to meet this standard in accordance with the approach suggested in the IMO G8 guidelines (and G9 guidelines, if the BWMS employs an active substance)
B -- likely to meet this standard if the more detailed ETV ballast water treatment test protocols were utilized
C -- may have the potential to meet this standard
D -- unlikely to or not possible to meet this standard

To date, all BWMSs adjudged to have reliable data have been tested in accordance with the G8 guidelines which provide only general recommendations for how to evaluae performance with respect to the D-2 standards. In late 2010, EPA's Environmental Technology Verification (ETV) Program has released the Protocol for the Verification of Ballast Water Treatment Technologies

(Version 5.0, EPA 2010). Although no BWMS has yet been tested under the ETV protocols, this protocol provides much more detailed instructions for how to conduct BWMS tests that are scientifically rigorous and statistically sound. In particular, the ETV protocol has significantly improved sampling procedures. The IMO G8 guidelines suggest collecting replicate samples with volumes of at least 1 m3 for the size class of organisms ≥ 50 µm in minimum dimension (nominally zooplankton). ETV, and others, have demonstrated that a time-integrated sampling approach with larger sample volumes will increase statistical confidence regarding whether zooplankton in sparse populations meet or exceed the D-2/Phase 1 standard (Miller et al., submitted; Lee et al., 2010, Section II). As such, although D-2 and Phase 1 standards are essentially the same, some BWMSs were given a score of 'A' if the data showed they met the D-2 standard by following the G8 guidance, and received a 'B' for Phase 1 if the number of living organisms was consistently low and it seemed very likely the BWMS would still meet the standard if ETV protocols (including larger, integrated samples) were used.

Regarding the discharge standard 10x more stringent than the D-2/Phase 1, the criteria used was whether the number of living organisms in all size classes was consistently low following testing (below the detection limit, often reported as zero, or not more than twice the standard). If so, the BWMS was given a 'C', indicating it had the potential to meet the standard. However, as described in the response to charge question 4 (Section 6), current testing methods do not provide the resolution required to conclude that 10x standards can be met.

For the most stringent standards, 100x and 1000x more stringent than D-2/Phase 1, if any living organisms in any size class were found following treatment, the BWMS earned a 'D'. This score indicates that it is extremely unlikely (or perhaps impossible) the BWMS could meet a stricter standard, again because the detection limit of the test methods used provide resolution to D-2/Phase 1, at best. For example, if one viable zooplankter was found in testing using volumes of 1 m3, the BWTT would be required to reduce the number of viable zooplankters to less than one in 10 m3 or 100 m3 to meet the 100x and 1000x standards, respectively.

After each subgroup member completed their individual, independent assessments, they discussed their scores collectively. All scores from the three primary reviewers were found to be identical and to be in complete agreement with general assessments by the two subgroup oversight members, as well as other members of the entire Panel. These consensus findings were used to create Table 4.1. Rather than present the scores from individual, commercial BWMS units or models, the Panel categorized the technologies by operation type (e.g., filtration + UV). The operation types were chosen from recently published, third-party data reports (Albert et al., 2010; Dobroski et al., 2010; Lloyd's List, 2010) in order to encompass all currently available operation types and to provide a standardized terminology. Thus, while the data packages from individual BWMS were initially examined and scored, the results were collapsed to represent a top-order status of the field. For a given operation type, if reliable data were available for more than one commercial BWMS, the scores given to the operation type were the highest scores of any of the individual BWMS. In this manner, Table 4.1 represents the greatest potential for each of the operational categories of technologies to meet various discharge standards.

Table 4.1: Performance of Ballast Water Management Systems

Type or Category of BWMS	# BWMSs	# Type Approval Cert	# Available/Reliable Data	D-2	P-1	10x	100x	1000x
Deoxygenation	2	0	0					
Deoxygenation+cavitation	1	1	1	A	B	C	D	D
Deoxygenation+bioactive agent	1	0	0					
Electrochlorination	2	1	0					
Electric pulse	1	0	0					
Filtration	1	0	0					
Filtration+chlorine	2	0	0					
Filtration+chlorine dioxide	1	0	1	A	B	C	D	D
Filtration+coagulation	1	1	0					
Filtration+UV	10	3	3	A	B	C	D	D
Filtration+UV+TiO2	1	1	1	A	B	C	D	D
Filtration+ultrasound	1	0	0					
Filtration+ozone+ultrasound	1	0	0					
Filtration+UV+ozone	1	0	0					
Filtration+electrochlorination	5	1	2	A	B	C	D	D
Filtration+UV+ozone+ electrochlorination	1	0	0					
Filtration+electrochlorination+ advanced oxidation	1	0	0					
Filtration+cavitation+ electrochlorination	1	0	0					
Filtration+-electrochlorination+ ultrasound	1	0	0					
Filtration+cavitation+ozone+ electrochlorination	1	1	0					

Type or Category of BWMS	# BWMSs	# Type Approval Cert	# Available/Reliable Data	D-2	P-1	10x	100x	1000x
Filtration+plasma+UV	1	0	0					
Filtration+cavitation+nitrogen+ electrochlorination	1	1	0					
Filtration+hydrocyclone+ electrochlorination	1	0	0					
Heat	1	0	0					
Hydrocyclone+filtration+ peracetic acid **	1	1	1					
Hydrocyclone+ electrochlorination	2	0	0					
Hydrodynamic shear+cavitation+ ozone	1	0	0					
Hydrocyclone+filtration+UV	1	0	0					
Menadione	1	0	0					
Mexel	1	0	0					
Ozone	1	1	0					
Ozone+cavitation	1	0	0					
Shear+cavitation+ozone	1	0	0					
Shear+cavitation+peracetic acid	1	0	0					
Totals	**51**	**12**	**9**					

Based on one or more reliable data sets, the type of BWMS:

(A) is demonstrated to meet this standard in accordance with G8/G9

(B) is likely to meet this standard

(C) has the potential to meet this standard
(D) unlikely or will not to meet this standard
** Not scored because the one manufacturer has withdrawn this BWMS from the market.

4.5 Assessment results

The results of this assessment are presented in Table 4.1 and interpretations of the findings are provided below. The pool of BWMS technologies is continuously growing, however, to reiterate for this assessment, 51 individual BWMSs were identified, information packages were provided for 15 individual BWMSs, and nine BWMSs were considered to have reliable data for an assessment of performance.

4.6 Response to charge question 1

The analysis described above formed the basis of our responses to charge Question 1a, 1 b, and 1 c; each of these sub-questions addresses different aspects of treatment capabilities for shipboard systems. These questions and our responses are summarized below.

Question 1 a: For the shipboard systems with available test data, which types or categories have been evaluated with sufficient rigor to permit a credible assessment of performance capabilities in terms of effluent concentrations achieved (living organisms/unit of ballast water discharged or other metric)?

Conclusion 1a: Five types or categories of ballast water treatment technologies (BWTTs) have been evaluated with sufficient rigor to permit a credible assessment of performance capabilities. These technology combinations are:

- Deoxygenation + cavitation
- Filtration + chlorine dioxide
- Filtration + UV
- Filtration + UV + TiO2
- Filtration + electrochlorination

BWMSs are still evolving with an ever-growing number of manufacturers developing treatment packages. Thus, this analysis of BWMS capabilities represents a snapshot in time. It is important to note the Panel received information for 51 BWMSs, representing different stages of development, testing, and operation. Of these, data packages for only nine BWMS were were deemed sufficiently complete and reliable for purposes of this assessment.
Conclusion 1a: Five types or categories of ballast water management systems (BWMSs) have been evaluated with sufficient rigor to permit a credible assessment of performance capabilities: Deoxygenation + cavitation, Filtration + chlorine dioxide, Filtration + UV, Filtration + UV + TiO2, and Filtration + electrochlorination. BWMSs are still evolving with an ever-growing number of manufacturers developing systems. Thus this analysis is a snapshot in time. It is important to note that 51 BWMSs were identified at different states of development, but only nine complete and reliable data packages were available to conduct this assessment.

Question1b: For those types or categories of systems identified in 1a, what are the discharge standards that the available data credibly demonstrate can be reliably achieved?

Furthermore, do data indicate that certain systems (as tested) will not be able to reliably reach any or all of the discharge standards?

Conclusion 1b: The same five types or categories of ballast water management systems listed above have been demonstrated to meet the IMO D-2 discharge standard, when tested under the IMO G8 guidelines, and will likely meet USCG Phase 1 standards, if tested under the more detailed ETV protocols. The detection limits for currently available test methods and approaches prevent a complete statistical assessment of whether BWMS can meet any stricter discharge standards. However, available data suggests that the same five types may be able to reach 10x D-2/Phase 1 for the > 50 µm and 10 – 50 µm size classes sometime in the near future, if both treatment performance and testing approaches improve. Available data also indicates that no current BWMS can meet the USCG Phase 2 standard, particularly for categories such as total bacteria. Because the only reliable data available to the Panel were on BWMSs that were able to meet D-2 standards, it is not possible to identify types or categories that will be unable to reliably reach any or all of the other discharge standards. In this regard, it is important to note that BWMS performance results obtained during R&D testing (in particular, failures to meet standards) are often not reported. This exacerbates the inability to assess BWMS performance capabilities.

Question 1c: For those systems identified above, if any of the system tests detected "no living organisms" in any or all of their replicates, is it reasonable to assume the systems are able to reliably meet or closely approach a "no living organism" standard or other standards identified in Table 4.1 of the White Paper, based on their engineering design and treatment processes?

To address this question, the phrase "no living organisms" was considered in two distinct ways: first, in a literal sense, to mean the sterilization of ballast water, and second, from a scientific perspective, to mean results below method detection limits.

Based on the test data provided for several BWMSs, it is clear numbers of live organisms in discharged ballast water are reduced dramatically relative to intake water and corresponding control water. Five distinct BWMS types have been demonstrated to meet the IMO D-2 and appear very likely to meet the USCG Phase 1standard (which demands, at minimum, a 4-log reduction from initial concentrations for the largest organism size class), not only in land-based testing but also under the challenging conditions presented on active merchant vessels during shipboard testing. However, levels of organism removal do not achieve sterilization or the complete removal of all living organisms. The identification of just one live organism would indicate non-sterile conditions, and all systems evaluated had at least one living organism in at least one treatment sample (and often more). Unfortunately, in some cases, this low number of live organisms is not an unreasonable artifact that might result from contamination from scientific sampling gear (nets, glassware, etc.) or human counting error.

Alternatively, it is possible to establish specific detection limits (e.g., 100, 10, 1.0, 0.1, live organisms m-3 or ml-1) associated with the methods used to collect the current performance data available and thus to conclude that, if numbers of live organisms are below those detection limits, they are statistically indistinguishable from zero or no living organisms. Efforts have been made to calculate the probabilities of meeting such specified detection limits, under certain assumptions, such as whether the organisms are randomly dispersed in space or spatially aggregated (see Lee et al. 2010 and Section 2 for details and examples). Not surprisingly, increased statistical power comes not only from increased sample size, but also from the difference between the mean established by regulation and the measured mean from a sample—which indicates the degree of compliance (or noncompliance). (See Section 2 for a more detailed discussion of sampling statistics and detection limits).

Conclusion 1c: It is not reasonable to assume that BWMS are able to reliably meet or closely approach a "no living organism" standard. Available data demonstrates that current ballast water management systems do not achieve sterilization or the complete removal of all living organisms.

4.7 <u>Response to charge question 2</u>

Question 2: Based on engineering design and treatment processes used, and shipboard conditions/constraints, what types of ballast water treatment systems can reasonably be expected to reliably achieve any of the standards, and by what dates? Based on engineering design and treatment processes used, are there types or categories of systems, which conceptually would have difficulty meeting any or all of the discharge standards?

A variety of BWMS types are being used to manage ballast water (Table 4.1). The data indicate that several types or categories are proving reliable and effective, and (Table 4.1) lists five types that have been demonstrated to meet the D-2/Phase 1 standard. The five BWMS also appear to be mature technologies, with multiple active vessel installations, and are commercially available. Interestingly, four of the five treatment approaches include a filtration step, although the inclusion of filtration does not necessarily ensure that the BWMS will meet discharge standards. A large majority of BWMSs also appear to be adapted from technologies long applied to drinking water or waste water treatment.

Given the data available, it is reasonable to assume that these same five systems have the potential to meet a 10 x D-2/Phase 1 standard in the near future. As noted above, we make this prediction based upon available data that show viable organisms sampled as low (usually, below detection limits) but improvements to test methods/approaches will be required to demonstrate conclusively that improved BWMSs meet standards beyond D-2/Phase 1. Given the data available, it is highly unlikely that any of the systems listed in Table 4.1 could provide organism removal to the level of 100x or 1000x the standard because all systems showed at least one observation of a living organism within the sample volumes as specified in IMO D-2 guidelines, thus clearly exceeding these more stringent standards. No BWMS reported zero living organism in all samples analyzed following treatment. In fact, most results showed an increase in total bacteria abundances after treatment, far exceeding discharge levels proposed in the USCG Phase 2 standards. We believe that ultimately different technologies, or treatment approaches, and sampling strategies will be needed to achieve these higher levels of removal. At this point in time, it is not possible to comment on the likelihood that the other treatment types listed will, or will not, be able to meet either the D-2/Phase 1or more stringent standards. All the BWMS types listed in Table 4.1 have likely shown some potential for reducing the number of ballast water organisms, but the data available for examination were deemed either to be absent or unreliable. As such, it is not possible to predict the eventual performance of these BWMSs.

Conclusion 2: Five types or categories of ballast water management systems can currently meet the IMO D-2 discharge standard and appear to meet USCG Phase I standard (Deoxygenation + cavitation, Filtration + chlorine dioxide, Filtration + UV, Filtration + UV + TiO2, and Filtration + electrochlorination) and it is possible that the same five types could meet 10x D-2/Phase 1 sometime in the near future if both treatment performance and testing methods and approaches (e.g., detection limits) improve. Nearly all of the 51 treatment types or categories evaluated are based on reasonable engineering designs and treatment processes, and most are adapted from long-standing industrial water treatment approaches. However, the lack of detailed information on the great majority of BWMSs prevents an assessment of limitations in meeting any or all discharge standards.

4.8 Environmental Effects and Vessel Applications: Additional Constraints and Considerations that influence BWMS performance

BWMS are still evolving with an ever-growing number of manufacturers developing systems. Although several BWMSs have received Type Approval Certification, and appear to safely (they have received final G9 approval) and effectively meet D-2/Phase 1 discharge standards (Table 4.1), there are several factors to consider beyond mechanical concerns and biological efficacy. Table 4.2 identifies broad environmental effects and vessel operational concerns. BWMS types identified in Table 4.2 as meeting at least the D-2/Phase 1 discharge standard and various treatment components being considered (e.g., filtration) are listed with potential limitations to operating under the various considerations. Four priority considerations, listed as Environmental Application or Vessel Application, were identified for Table 4.2: Salinity (the ability to treat fresh, brackish and marine water), Temperature (the ability to work effectively in a variety of temperatures from warm equatorial to cold polar water), Ballasting Rate (the ability to treat water moving at a variety of flow rates from < 200 m3 hr-1 to > 4,000 m3 hr-1), and Ballast Volumes (the ability to treat total volumes of ballast water from < 1,000 m3 to > 50,000 m3). Each application was designated either as requiring special consideration or not having obvious limitations for the various BWMS type or treatment approach. Additional explanation is also provided in the table.

Table 4.2. Operational considerations affecting ability of BWMS to work properly under a range of conditions. Note the table represents only higher-order considerations.

	Operational Considerations			
	Environmental Application		Vessel Application	
Category of BWMS	**Range of Salinities**	**Range of Temperatures**	**Range of Ballasting Rates**	**Range of Ballast Volumes**
Deoxygenation+cavitation	No obvious limitation	No obvious limitation	No obvious limitation	No obvious limitation
Filtration+chlorine dioxide	No obvious limitation	No obvious limitation	Filtration rate may be limiting	No obvious limitation
Filtration+UV	No obvious limitation	No obvious limitation	Filtration rate and UV transmittance may be limiting	No obvious limitation
Filtration+UV+TiO2	No obvious limitation	No obvious limitation	Filtration rate may be limiting	No obvious limitation
Filtration+electrochlorination	Addition of brine may be required in freshwater	Neutralization may be required in cold water	Filtration rate may be limiting	No obvious limitation
Treatment Components				
Electrochlorination	Addition of brine may be required in freshwater	Neutralization may be required in cold water	No obvious limitation	No obvious limitation
Filtration	No obvious limitation	No obvious limitation	Filtration rate may be limiting	No obvious limitation
Heat	No obvious limitation	No obvious limitation	No obvious limitation	No obvious limitation
Hydrocyclone	No obvious limitation	No obvious limitation	Flow rate may be limiting	No obvious limitation
Ozone	Addition of brine may be required in freshwater	Neutralization may be required in cold water	No obvious limitation	No obvious limitation
Ultrasound	No obvious limitation	No obvious limitation	Flow rate may be limiting	No obvious limitation
Peracetic acid	No obvious limitation	Neutralization may be required in cold water	No obvious limitation	No obvious limitation
Shear/cavitation	No obvious limitation	No obvious limitation	No obvious limitation	No obvious limitation

Another important vessel consideration is impacts of treatments on ballast tank and piping coatings and substrate corrosion rates. Nearly all systems that alter the chemical composition or reactivity of ballast water (e.g., heat, oxidants and deoxygenation) can potentially affect corrosion of ship structures, piping, fixtures and protective coatings. To a great extent, the potential effects of these BWMS have not been consistently evaluated across the various modes of corrosion, including uniform or localized corrosion, nor for potential interactions with corrosion control systems including protective coatings and cathodic protection systems. Some BWMSs have provided data that indicate negligible impacts on corrosion rates or even improvements. For example, deoxygenation, if operated properly, can dramatically reduce uniform corrosion rates, but alternatively may result in increased corrosion rates due to either the cycling hypoxic and aerated conditions or the formation of corrosion causing sulfate reducing bacteria if anoxic conditions are reached. Similarly, other BWMS utilizing strong oxidants have been evaluated as having apparently negligible effects on coatings and steel corrosion rates. However, it is also well documented in the wastewater and marine vessel industry that continuous exposure to high doses of some oxidants, such as halogenated oxidants, can cause severe corrosion rates (depending on the specific oxidant, its concentration and contact period). On the other hand, while heightened corrosion rates may be experienced shortly after treatment, corrosion rates on whole may not be significantly affected if the oxidant concentration declines rapidly.

Corrosion is already a significant concern for vessels operating in saltwater environments. As such, coating failures and steel wastage are currently incorporated into periodic surveys and vessel service periods. In the end, an increase in corrosion rates will impact the maintenance and repair costs borne by the vessel owner. These potential increases in cost will need to be factored by that owner in selecting a BWMS. In addition, corrosion control and mitigation strategies such as coatings and cathodic protection should also be carefully considered since either or both of these may be employed to offset any increased corrosion concerns. Although comprehensive assessments have not been conducted for all BWMSs, no major damage or casualties related to corrosion have been identified to date for BWMSs installed on ships.

In addition to specific environmental and vessel applications, vessel type and vessel operations can dictate BWMS applicability. Although there are a multitude of vessel designs and operation scenarios, there are a few important examples of specific constraints that can greatly limit treatment options. Perhaps the most dramatic limitations are found with the Great Lakes bulk carrier fleet that operates vessels solely within the Great Lakes with large volumes of fresh, and often cold, ballast water ('Lakers'). The vessels in this fleet have ballast volumes up to 50,000 m3, high pumping rates (up to 5,000 m3 hour-1), uncoated ballast tanks, and some vessels have separate sea chests and pumps for each ballast tank. A further confounding issue is that voyages taken by Lakers average four to five days, with many less than two days. Given these characteristics, a number of limitations are imposed: electrochlorination and ozonation may only work in freshwater with the addition of brine (in particular Cl and Br, respectively); oxidizing chemicals may increase the corrosion rate of uncoated tanks; deoxygenation and chemical treatments that require holding times to effectively treat water (or for the breakdown of active substances) may not be completely effective on short voyages; and the space and power needed for the required numbers of filtration + UV treatments may simply not be available.

Another example of vessel-specific constraints is the sheer size of some vessels and the cargo they carry. Very Large Crude Carriers (VLCC) and Ultra Large Crude Carriers (ULCC) can carry up to 100,000 m3 of ballast and can fill or discharge ballast water at over 5,000 m3 hour-1. While various BWMS may be modular (perhaps providing the ability to add several units in a manifold design or in sequence), systems that include a mechanical separations stage (e.g., filtration, hydrocyclone) or exposure to UV or sonication may have difficulty addressing these large volumes and flow rates. Furthermore, given the hazardous nature of the cargo carried on these ships (and other similar vessels, such as Liquefied Natural Gas carriers), restrictions on the placement of a specific BWMS may apply and system components will likely have to satisfy classification society requirements for explosion proof and intrinsically safe construction, which might be more difficult for some treatment types than others.

A final example is the treatment of ballast water on the tens of thousands of unmanned barges in the U.S. that would fall under the ballast water discharge regulations. Inland waterways and coastal barges are not self-propelled, but rather are moved by towing or pushing with tugboats. Because these vessels have been designed to transport bulk cargo, or as working platforms, they commonly use ballast tanks or fill cargo spaces with water for trim and stability, or to prevent excessive motions in heavy seas. However, the application of BWMSs on these vessels presents significant logistical challenges because they typically do not have their own source of power or ballast pumps and are unmanned.

Conclusion 3: While several BWMSs appear to safely and effectively meet D-2/Phase 1 discharge standards, there are several factors to consider beyond mechanical and biological efficacy. A variety of environmental (e.g., temperature and salinity), operational (e.g., ballasting flow rates and holding times), and vessel design (e.g., ballast volume and unmanned barges) parameters will impact the performance or applicability of individual BWMSs.

5. RESPONSE TO CHARGE 3: SYSTEM DEVELOPMENT

This section addresses issues raised in Charge Question 3 regarding further development of ballast water treatment systems, especially technological options for potential improvements and impediments to improvement..

5.1. Charge Question 3a

For those systems identified in questions la and 2, are there reasonable changes or additions to their treatment processes which can be made to the systems to improve performance?

Response
In 2004 the International Maritime Organization (IMO) adopted the Ballast Water Convention that provided a discharge standard commonly referred to as "D-2." This published standard has provided a stable target to support the research, development, testing, and evaluation of technologies and practices to treat ballast water. Using this standard, ballast water management system (BWMS) development cycles have balanced the following:

- Integrating technology within marine vessel arrangements, weight and stability constraints, electrical distribution and piping systems, and automation control systems.
- Integrating technology operations within marine vessel operational demands such as ballasting rates and volumes, logistics requirements such as reliable chemical supply chains and service/support centers, safe operations such as hazardous rated equipment and chemical handling procedures, operational training.
- Tuning the technology to an acceptable level of disinfection byproducts, residual toxicity, within the limits of practical integration and compliance with the efficacy standard.
- Packaging the technology for a commercially competitive market considering life cycle costs, equipment reliability and maintainability, and mariner familiarity or acceptability of equipment.

In general, it appears that the development cycle of a given BWMS stops once testing indicates that the D-2 standard has been met. There are reasonable changes, requiring additional expense and complexity, that could provide incremental improvements in efficacy. The following comments on possibilities to improve performance do not consider possible ship-board constraints (which are addressed in response to Charge Question 3.b. Part A):

- **Deoxygenation + cavitation**. Severe hypoxia ($[O_2]$ <1 mg/L) has already been established in these systems and in and of itself, cannot be improved upon. Improvements may emerge by shortening the time to severe hypoxia and increasing hold time. In addition, increasing the degree of cavitation may increase performance by greater mixing and thus exposure of organisms to severe hypoxia.

- **Mechanical separation + oxidizing agent**. Separation (i.e., physical removal of organisms) could be optimized and contact time for oxidizing agent exposure could be increased.
- **Mechanical separation + UV.** Separation could be optimized and contact time/dosage with UV could be increased.

Combinations of some systems above may result in improved performance, and we recommend that trials be conducted to determine optimum combinations. "Tweaking" existing technologies, however, will only result in incremental improvements toward meeting published standards. New technologies will be needed for 100X and 1000X IMO regulations, and shipboard systems should not be the only possibilities considered (see response to Charge Question 4).

Meeting More Stringent Standards

As more stringent discharge standards are considered, technological development can consider either incremental improvements to existing applications, or new approaches utilizing technology that has not typically been applied on marine vessels. As suggested earlier in this response to the charge question, incremental improvements offer the fastest path to meeting higher discharge standards by "turning up the dial." New approaches, possibly from the wastewater treatment industry, may also reach those standards, but will take more time to develop and trial to determine practicality and cost impacts.

These more stringent standards also increase the importance of process control, because they allow little to no room for error. In a 5,000 m^3 discharge, for example, the D-2 standard allows up to 50,000 organisms >50 µm in minimum dimension. Inherent in this relatively high value is some allowance for:

- Organisms released during treatment system start-up or shut-down.
- Intermittent periods that exceed challenge conditions due to "patchiness" of organisms, as could be caused by ballast uptake in an algal bloom, or while discharging the bottom of a ballast tank that has a high load of sediment and settled organisms.
- Lag time as control systems adjust to changing ballast pumping flow rates, increases in uptake water turbidity, or other changes due to the natural environment or marine vessel operational demands.

More stringent discharge standards, however, ones requiring a 5- or 6-log reduction, reduce the zooplankton allowance for this example to 5,000 or 500 organisms, respectively. Meeting this standard may require fundamental changes to ballasting routines that include separate dedicated uptake and discharge piping, and recirculation loops to verify efficacy prior to ballast water discharge.

In the following two sections, we separately consider incremental improvements and new approaches to ballast-water treatment. The former elaborate on the "bullet points" listed in the "Response" section above. The latter are offered with the intent of considering long-term improvements in performance of ballast-water treatments.

Incremental Improvements

Incremental improvements to existing technologies are based on the concept of "turning up the dial." The development cycle for these incremental improvements unfortunately is not simple. This approach needs to consider two aspects: it may not be possible or practical to further improve the baseline technology, and the improvement in efficacy could fundamentally alter other aspects of the technology development cycle, i.e., life cycle costs, integration, or residual toxicity. In summary, these incremental improvements are not always simple or straightforward. The following sections consider the baseline technologies identified in Table 1 (See Group 1 Table). For each, the improvements for increased efficacy are identified, and then challenges to the development cycle are discussed.

Mechanical separation + UV

Ultraviolet radiation (UV) is widely deployed in industry and used on marine vessels to disinfect potable, technical, and waste water streams. In the context of ballast-water treatment, several technologies have successfully demonstrated application of UV.

The efficacy of UV is dependent on matching the wavelength to the targeted organism and pathogens, intensity of the radiation, accounting for transmissivity of the water, and the resulting exposure time. Effective application of UV is further dependent on the physical configuration and fluid dynamics of the UV chamber to ensure adequate intensity and exposure time to the entire flow stream. Of the three classes of UV radiation, UVA penetrates water the best but is less lethal. UVC penetrates water the least but is most lethal and UVB in intermediate in penetration and lethality (Vantrepotte and Mélin 2006).

To meet the D-2 standard, technology suppliers have developed and trialed their systems to balance these multiple process components. In general, efforts to meet a more stringent standard will require larger UV chambers, more significant pre-treatment of the ballast water, and more complex controls. In short, it is possible to increase the efficacy of existing systems beyond the D-2 standard, but only with more space, radiation intensity, complexity, and expense.

It may be possible to deploy an "oversized" treatment system. For example, a ballast system that runs at 800 m^3 per hour could be paired with a treatment system rated for 1,000 m^3 per hour, thereby effectively increasing UV exposure by 20%. Analysis would be needed to determine how much the system's efficacy was increased, and to assure the fluid dynamics of the UV chamber were not adversely impacted.

Similar to use of an "oversized" treatment system, the intensity of the UV lamps could be increased to improve efficacy. Also, the length of time the ballast water was exposed to UV could be increased by increasing the size of the chamber relative to the ballasting rate. Such improvements would directly impact system cost, and size of the equipment.

It is possible to stage several UV chambers in series. The obvious impact of such an effort would be a substantial increase in cost, required space, and maintenance. This approach, however, offers to improve several aspects of a UV-based system:

- Use of multiple chambers decreases the chance that an organism can "slip" past treatment, assuming each chamber on its own is capable of reaching the required standard.
- Multiple chambers may allow a supplier to utilize different lamps emitting different wavelengths (UVA to UVC). Individual chambers may be "tuned" to a spectrum targeting certain kinds of organisms.
- Multiple chambers would allow increased exposure time of organisms to the UV.

Transmissivity (clarity) of ballast water and exposure to organisms can be increased by employing higher levels of mechanical separation upstream of the UV chamber. Further, flocculants such as alum and other means could further clarify the ballast water prior to its entry into the UV chamber. Higher levels of mechanical separation will require significant increases in expense and space. In addition, advanced filtration is likely to significantly increase system backpressures, resulting in a need for higher head ballast pumps and additional electrical power.

<u>Deoxygenation</u>

Two Type Approved ballast water treatment systems utilize deoxygenation as part of their treatment process. However, both of these systems also rely on multiple additional processes to meet the D-2 standard.

One system lowers the oxygen by pumping low-oxygen exhaust gas from a purpose-built burner into the ballast-water stream through a venturi device. The efficacy of this system is reliant on the rapid application of this gas stream, the creation of carbonic acid resulting from carbon dioxide in the gas stream, which lowers pH making the low oxygen environment more lethal, and the mechanical effect of the venturi on the passing organisms.

This system lowers the oxygen level to about 2% by volume, or about 0.7 mg/L, utilizing a variation of traditional tank-ship combustion-based inert-gas generators. The traditional units typically produce a 5% oxygen level, about 1.8 mg/L. Further optimizing a combustion-based unit to provide lower oxygen levels may not be practical given the combustion process. As a reference point, a 2 mg/L oxygen level is considered the upper boundary for environmental hypoxia and the point of mortality for sensitive species. Very few metazoans can survive <1 mg/L oxygen for longer than 24 hours (Vaquer-Sonyer and Duarte 2008).

A second system lowers oxygen levels through the use of a nitrogen generator. The generator uses a membrane to filter ambient air, resulting in high quality nitrogen gas. The process also includes mechanical separation, cavitation, and an electrodialytic disinfection process.

Nitrogen generators are widely deployed in industry and in some marine applications. They are generally considered expensive and high consumers of electrical power in shipboard applications. It is possible to produce very high quality nitrogen gas, approaching 99.9% pure, but at significant space, capital cost, and electrical power demands.

Due to the complexity of treatment systems that utilize deoxygenation, the impact of incremental improvements on efficacy is not obvious. In fact, some changes might decrease the system's efficacy or worse, resulting in unanticipated adverse conditions, e.g., higher populations of sulfate-reducing bacteria and a subsequent increase in steel corrosion rates. With respect to deoxygenation, therefore, it is not clear whether an effort to "turn up the dial" will result in meeting a more stringent standard. Relative to lethality for metazoans, there will be little to no difference between a 2 mg/L oxygen level and 1 mg/L for the same contact period. Extending holding time would be more efficient than additional efforts to reduce oxygen below 1 mg/L. Finally, there is some evidence (Tamburri, pers. comm.) that faster transitions to severe hypoxia are more lethal.

<u>Oxidant-Based Systems</u>

Oxidant-based systems introduce an oxidizing agent, such as chlorine, into the ballast-water stream. For the purposes of mechanical considerations, this process includes adding chemical in bulk, on-site manufacture of sodium hypochlorite or similar chemicals, and on-site production of ozone gas. Oxidant-based systems generally target a level of residual oxidant in the treated ballast water.

As the organic-matter content of ambient water taken up as ballast water varies, so will the consumption, or oxidant demand, of the oxidant introduced by the treatment system. After an initial instantaneous demand is consumed, any remaining oxidant will be pumped with the ballast water into the vessel's ballast tanks. There the water is held for a prescribed length of time at the targeted residual oxidant concentration. The residual will decay over time as a function of many factors, including its initial concentration, salinity, temperature, motions of the vessel, and configuration of the ballast tank and venting system. Depending on predicted or measured oxidant levels in the ballast water, a neutralizing agent may be applied before or during its discharge to the environment.

The efficacy of oxidant-based systems is a function of concentration of the residual oxidants and the holding time. Improvements to efficacy include: increasing initial oxidant concentrations; maintaining a higher oxidant concentration during the holding period; and increasing the holding period or contact time. These three options are considered in the following subsections. Combining the oxidant with other processes is considered a combination approach, and is considered in a later section.

>>Increasing initial oxidant concentrations

Determining the initial oxidant concentration to reach the required efficacy is part of the "art" of a ballast-water treatment system. IMO Basic and Final Approval applications provide values for various treatments: 2.5 mg/L total residual oxidant (TRO) for System "A"; 3.16 mg/L chlorite ion for System "B"; 15 mg/L TRO as Cl_2 for System "C"; 1.0 parts per million of free active chlorine for System "D"; and 2.2 and 4.2 mg/L of ozone and TRO, respectively, for System "E".

Several oxidant-based systems also use some form of mechanical separation, which serves to remove larger organisms and some particulate organic matter and thereby reduces oxidant demand. Regardless of mechanical separation's effectiveness, however, residual oxidants and other disinfection byproducts remain the active substances. As such, mechanical separation may reduce the amount of chemical required, but is not expected to improve the efficacy of the oxidant. Tertiary impacts, such as damage to organisms' membranes incurred during the mechanical separation process, and the membranes' subsequent interaction with oxidant-based systems, are difficult to analyze and therefore not obvious as an incremental improvement of existing technologies.

It is possible with existing systems to "turn up the dial" and increase the amount of oxidant introduced to the ballast water, which should result in increased efficacy. Increasing oxidant concentrations simply requires that a higher capacity ballast-water treatment system be installed. For example, concentrations could be increased 50% by installing a system rated for 1200 m^3 per hour on a vessel that pumps ballast water at 800 m^3 per hour. Such an installation will demand larger space and weight allowances, more power, and higher capital and operating costs. In general, integration of higher capacity systems should be possible for new vessel designs, and more challenging for existing vessels on a retrofit basis.

Higher oxidant levels in the ballast water can have a significant and negative impact on piping-system components and tank-coating systems. Valve packing, flange gaskets, and pump seals are made of a variety of materials, some of which are not compatible with oxidants at low concentrations, and less so at increasingly higher ones. Impacts on tank coatings are not yet well understood. TRO levels up to 10 mg/L may be compatible with typical, intact, ballast-tank marine coatings. Coatings are frequently not intact, however, as they wear over time or are not applied in freshwater shipping applications. Corrosion of exposed carbon-steel structures can lead to structural failures and repairs that are expensive and complex. Increased oxidant levels, therefore, will likely increase the rates of coating failures and corrosion of exposed carbon-steel structure.

Higher oxidant levels also increase safe-handling concerns on board vessels through resultant hydrogen generation, additional bulk chemicals to handle and store, and increased times to make confined tank spaces safe for entry for inspection and repair work. These concerns can be handled through procedures and plans, but at the expense of increased time and effort.
As higher levels of oxidants are introduced into ballast water, complex chemical reactions take place, resulting in potentially harmful disinfection byproducts. These byproducts are impacted by the interaction between the oxidant level and characteristics of the uptake water such as its organic load, alkalinity, salinity, and chemical contaminants. Further testing and analysis will be needed to determine whether these byproducts need to be or can be effectively neutralized, such that the ballast water will have an acceptable toxicity level prior to its discharge.

>>Maintaining or increasing oxidant concentrations
Most oxidant-based systems rely on residual-oxidant levels adequate to meet the D-2 standards and maintaining that concentration for the duration of the holding period. The hold time of ballast water can vary significantly, however, and schedule, weather, equipment failure, and cargo-handling changes frequently result in longer- or shorter-than-expected hold times. As hold times increase, the residual-oxidant concentrations decay, which also reduce detoxification costs. Most efficacy testing has occurred during a regimented holding period, typically for two to five days. In reality, ballast-water hold times routinely range from one day to several weeks. In fact, some ballast tanks can remain full, or partially full, for many months or even years.

There has been little development or testing of systems that monitor and maintain a specific oxidant level in ballast-water tanks. Indeed, automated monitoring of oxidant levels in ballast-water tanks is not currently practiced. Continuous or periodic monitoring would require either a network of sensors installed in the tanks or a means of drawing a liquid sample on a periodic basis to a remote monitoring device. Either approach requires significant cabling, possibly tubing and pumps, monitoring equipment, and data-recording devices.

Current practice to maintain an oxidant level, if done at all, is to "top up" a ballast tank, i.e., to partially discharge its contents, then refill with freshly treated water. The objective is to achieve the desired oxidant level by mixing the "new" water having a high concentration of oxidant with the water remaining in the tank. Such efforts are similar in mechanical function to ballast-water exchange, would likely be performed while the vessel is at sea, and carry with them the same significant safety concerns regarding vessel stability.

A more reliable and safer approach for topping up oxidant levels will require new systems that are not currently available. Such systems might include chemical dosing lines to deliver an external supply to each ballast tank, combined with circulation devices internal to each ballast tank.

>>Increasing the hold period

Increasing the hold time of the ballast water while maintaining a certain oxidant level would likely increase efficacy. However, it is ship operations that will dictate the duration of this hold time for most ballast water tanks. In particular, the largest mid-body, ballast-water tanks almost always have to be discharged while tank ships or bulk carriers are being loaded. As such, the treatment process must account for the expected hold period, but likely will not have the ability to alter it.

>>Other methods

It is well known in other applications (e.g., White, 1972) that pH and the presence of ammonia nitrogen (inorganic and organic) can influence the biocidal effectiveness of chlorine. While altering ammonia N is likely not to be feasible, it is possible that altering pH may enable further optimization of chlorine-based disinfection technologies.

>>Summary

Existing oxidant-based systems have been developed to meet the D-2 standard, and several have gained international approvals. Their efficacy could be increased by increasing initial residual oxidant levels in ballast water during uptake. However, testing would need to be conducted to understand how much this efficacy would be increased by these higher doses. In addition, toxicity impacts from the disinfection byproducts of these higher doses must be studied before proceeding. Increasing residual oxidant levels will impact the vessel through greater demands for space, weight, power, and capital and operating expenses; in addition, they will increase piping-system compatibility issues, ballast-tank corrosion rates, and safe-handling concerns. It may be possible to increase efficacy by maintaining residual oxidant levels during holding time in the ballast-water tanks. Current systems, however, have only rudimentary methods for performing such operations. New methods will need to be developed and trialed to determine their practicality and effect.

<u>Mechanical Separation and Cavitation</u>

Ballast-water treatment systems have extensively utilized mechanical separation as a primary step for other processes such as ultraviolet radiation or oxidants. Mechanical separation serves multiple purposes that vary according to the treatment's disinfection processes: screening of larger organisms that may be resistant to disinfection; reduction of organic matter to reduce oxidant demand; and reduction of turbidity to increase transmittance of ultraviolet system.

Mechanical separation also has a secondary effect of physically damaging some of the organisms as they pass through the device. This effect may inactivate or kill the organisms or weaken their cellular structure such that effective disinfection is more easily achieved. In this way, mechanical separation is similar to cavitation devices designed to impart physical damage.

Traditional seawater filtration on vessels has been limited to protecting mechanical devices in the piping system. For example, seawater might be "screened" to a one-eighth inch opening (3.175 mm) to protect the narrow passages of a heat exchanger. Recently, however, several common and proprietary devices have been developed for filtering and imparting cavitation effects on ballast water as part of the treatment process: variations on back flushing of traditional screen filters; vibrating disc filters; multi hydro-cyclone; and various cavitation devices. In general, the filter units target removal of particles above 40 or 50 µm and have significant waste streams that are returned to the ambient water. Typically, filtering takes place on ballast water uptake only.

The efficacy levels of these mechanical separation devices are advertised in percentage removal. For example, two companies claim filtration rates of approximately 90 percent removal of zooplankton. These removal levels, although essential to support the disinfection process, by themselves are far below the D-2 standard for the size class $\geq$ 50 µm.

It is not reasonable to expect incremental improvements in mechanical separation devices to offer significant improvements in efficacy over the D-2 treatment standard. Such improvements will require the application of media filters, membrane filters, or other devices that have not yet been practically applied to ballast-water treatment. Cavitation devices similar to filters cannot meet the D-2 standard alone. It is not clear if improving these cavitation devices will have a significant impact on the efficacy of the combined processes.

<u>Combination Technologies</u>

Most ballast-water treatment systems, even those with a single primary component, are actually combination technologies. For example, one company's product is primarily a deoxygenation system, but also has other effects at work: a venturi device mechanically damages some of the organisms as would a cavitation device, and carbon dioxide forms carbonic acid, lowering the pH of the water. Another commercial system is advertised as a combination technology that includes filtration, ultraviolet radiation, and free radicals.

It is difficult to understand fully the interactions of combined ballast-water treatment technologies. For example, one company's system combines filtration, cavitation, ozone, and injects sodium hypochlorite. With four "primary" technologies at work, which one(s) should be the focus for "turning up the dial" to reach a higher efficacy standard? Further complicating matters is the high physical and chemical variability in the ballast water itself, and how it reacts with each technology and combination thereof.

The development of combination technology to date is a result of research and testing. It is important to note that once a technology has shown promise to meet the D-2 standard, its development has been stopped in order to allow the device to undergo certification efforts. As such, it is reasonable to assume that combination technologies can be incrementally improved in terms of efficiency of operation (less power, less cost, more reliability) and efficacy. Due to the complex interactions of these technologies, however, improving and optimizing their combinations can only be speculative until the concepts are trialed.

New Approaches – Overview and perspective on more stringent standards

Ballast-water discharge standards 1000 times more stringent than the D-2 standard are being considered by the USCG. As discussed above, however, it is unlikely current management approaches and treatment technologies will meet these significantly more challenging standards.

In part, the inability to do so stems from design characteristics of present-day treatment technology, which is placed “on top” of existing ballast-piping systems. Thus, standard ballast pumps and piping systems are used, with treatment calling for addition of filters, passage through UV lamps or cavitation devices, and possibly chemical-injection ports. Ballast water is taken up, held, and discharged in essentially the same manner as in the past. Furthermore, compliance monitoring and enforcement programs are currently under development. As they are revised, they will likely reveal “gaps” in ships’ ability to maintain ballast water in a “treated” status during long holding durations, and under circumstances for which treatment-system suppliers have not designed their systems.

To meet more stringent standards, and to account for the variety of circumstances a vessel’s ballast water experiences, new approaches to management and new technologies will be required. The following subsections develop a vision of these new approaches and technologies by:

- Placing more stringent standards into perspective for vessels’ ballast capacities.
- Identifying key technology and management considerations for meeting more stringent standards.
- Identifying key elements of an idealized shore-side plant for treating ballast water.
- Conceptualizing new management approaches and technologies for meeting more stringent standards on board a vessel.

<u>Perspective on More Stringent Standards</u>

Multiple ballast-water treatment systems have demonstrated successful compliance--under G-8 testing conditions--to the IMO D-2 standard. The D-2 standard is a 4-log reduction in the number of zooplankton-sized organisms, those $\geq$ 50 µm in minimum dimension, relative to the “challenge water” called for in US EPA’s Environmental Technology Verification (ETV) protocol for testing ballast-water treatment systems (Text Box 4.1). For a very large crude carrier (VLCC) tanker, this standard allows a treated water volume of 90,000 m^3 to contain a maximum of 900,000 zooplankton (Table 4.1).

The USCG's proposed Phase 2 standard for zooplankton is a 7-log reduction from the ETV challenge-water conditions, equivalent to a 99.99999% reduction, referred to in reliability engineering as "seven-nines" [Equation 1]. For the VLCC example, this standard limits the discharge of viable zooplankton to a maximum of 900 individuals, fewer than half the number of zooplankton contained in a 20-liter bucket of ETV challenge water [Equations 2 and 3].

ETV Challenge Water Conditions

Dissolved Organic Matter (DOC): 6 mg/L
Particulate Organic Matter (POM): 4 mg/L
Mineral Matter (MM): 20 mg/L
Total Suspended Solids = POM + MM: 24 mg/L
Temperature: 4 – 35 °C
Two of the following water types: Fresh (Salinity <1 PSU), Brackish (Salinity 10-20 PSU), Marine (Salinity 28-36 PSU)

Organism Size Class: ≥ 50 µm
Total Concentration: 10^5 organisms/m^3
Diversity: 5 species across 3 phyla

Organism Size Class: ≥ 10 µm and < 50µm
Total Concentration: 10^3 organisms/mL
Diversity: 5 species across 3 phyla

Organism Size Class: <10 µm
Total Concentration: 10^3/mL as culturable, aerobic, heterotrophic bacteria

Consider these values in the context of vessel onboard practice. VLCCs typically discharge ballast water at 5,000 m^3 per hour. At this rate, one second of discharge yields 1.39 of water. Assuming ETV challenge water conditions, this one second of discharge would contain 139,000 zooplankton, a number that would exceed the allowable discharge for the entire VLCC ballast capacity by 1.5 times (D-2/10 Standard), 15 times (D-2/100 Standard), or 154 times (D-2/1000 Standard).

$$\boldsymbol{Phase\ 2\ Reduction}\ (percentage\ reduction\ organisms\ \geq 50\ \mu\text{m}) = 1 - (Maximum\ Allowed\ by\ Phase\ 2\ Rule\ \div Minimum\ Count\ in\ ETV\ Challenge\ Water)$$
[Equation 1]

$$\boldsymbol{Phase\ 2\ Reduction} = 1 - (1\ per\ 100\ cubic\ meters\ \div 100{,}000\ per\ cubic\ meter) = 1 - (0.010\ \div 100{,}000) = 99.99999\%$$ [Equation 1]

$$\boldsymbol{Phase\ 2\ Maximum\ Discharge}\ (number\ of\ organisms\ \geq 50\ \mu\text{m}) = Discharge\ Standard\ \times Ballast\ Discharge\ Volume$$ [Equation 2]

$$\boldsymbol{Phase\ 2\ Maximum\ Discharge\ for\ VLCC} = 1\ per\ 100\ cubic\ meter\ \times\ 90{,}000\ cubic\ meters = 900\ organisms\ \geq 50\ \mu\text{m}$$ [Equation 2]

$$\boldsymbol{Challenge\ Water\ (Raw\ Seawater) Minimum\ Concentration}\ (number\ of\ organisms \geq 50\ \mu m = Challenge\ Water\ Criteria \times Ballast\ Water\ Volume\ \text{[Equation 3]}$$

$$\boldsymbol{Challenge\ Water\ Minimum\ Concentration\ for\ 20\ liter\ Bucket} = 100{,}000\ per\ cubic\ meter \times 20\ liters = 2{,}000\ organisms \geq 50\ \mu m\ \text{[Equation 3]}$$

$$\boldsymbol{Phase\ 2\ Allowable\ Discharge\ VLCC} = 1\ per\ 100\ cubic\ meter \times 90{,}000\ cubic\ meters = 900\ organisms \geq 50\ \mu m\ \text{[Equation 2]}$$

Similar challenges are also apparent for smaller-capacity vessels. Under Phase 2, the number of zooplankton allowed to be discharged by a small containership or a typical passenger ship would be fewer than 35 individuals, equivalent to the number in a volume of ETV challenge water water that would fill a glass of beer (Table 4.1).

Table 4.1 – Zooplankton Counts for Water and Increasing Log Reductions from D-2 Standard. The USCG's proposed Phase 2 standard is represented by in the column labeled "D-2/1000".

Volume Basis	Volume *(m3)*	Rate *(m3/hr)*	*Viable Organisms >50 um (Seawater per US ETV)* Seawater	IMO D-2	D-2/10	D-2/100	D-2/1000
Test Standards	1.00E+00	NA	1.00E+05	1.00E+01	1.00E+00	1.00E-01	1.00E-02
VLCC Tanker	9.00E+04	5.00E+03	9.00E+09	9.00E+05	9.00E+04	9.00E+03	9.00E+02
Great Lakes Bulk Carrier	4.40E+04	1.00E+04	4.40E+09	4.40E+05	4.40E+04	4.40E+03	4.40E+02
Handymax Bulk Carrier	1.80E+04	1.30E+03	1.80E+09	1.80E+05	1.80E+04	1.80E+03	1.80E+02
Panamax Container	1.70E+04	5.00E+02	1.70E+09	1.70E+05	1.70E+04	1.70E+03	1.70E+02
Feedermax Container	3.50E+03	4.00E+02	3.50E+08	3.50E+04	3.50E+03	3.50E+02	3.50E+01
Passenger Ship	3.00E+03	2.50E+02	3.00E+08	3.00E+04	3.00E+03	3.00E+02	3.00E+01
ETV Testing Tank	2.00E+02	2.00E+02	2.00E+07	2.00E+03	2.00E+02	2.00E+01	2.00E+00
VLCC Pipe (2.2 meters)	1.39E+00	5.00E+03	1.39E+05	1.39E+01	1.39E+00	1.39E-01	1.39E-02
Bucket (20 liters)	2.00E-02	NA	2.00E+03	2.00E-01	2.00E-02	2.00E-03	2.00E-04
Beer Glass (0.4 liters)	4.00E-04	NA	4.00E+01	4.00E-03	4.00E-04	4.00E-05	4.00E-06

Table 4.1 relates zooplankton treatment standards to maximum numbers of viable organisms for various volumes. The top row provides organism counts in one m^3 *for water, as per ETV challenge-water conditions, the D-2 standard, and finally for successive log reductions beyond D-2. Several vessels are listed showing typical ballast-water volumes and flow rates. For each volume, the number of organisms in water and the maximum number of organisms allowed for each of the discharge standards are tabulated.*
Table 4.1 also indicates the number of zooplankton in ETV challenge-water volumes equivalent to a beer glass, a bucket, and that displaced by one second of untreated discharge from a VLCC. The highlights indicate when the glass, bucket, or discharge contains more viable organisms than the total volume of a treated vessel discharge.

The practical implication of these more stringent standards is that piping systems must be carefully designed to avoid the discharge of any untreated ballast water, however minimal the volume. This implication has the following requirements:

- Separate uptake and discharge ballast-water piping may be required. Current standard practice is to use a common piping system for both uptake and discharge.
- To allow for any brief interruptions in the treatment process during start-up or shut-down, treated ballast water may need to be re-circulated to confirm its treatment status before discharge.

<u>Key Technology and Management Considerations for Meeting More Stringent Standards</u>

In considering future management approaches and technologies, maximizing energy efficiency is increasingly important for vessels. This strategy is driven not only by rising fuel costs, but also by possible valuations on air emissions such as sulfur oxides, nitrogen oxides, particulate matter, and other contaminants. Further, a carbon-taxing scheme is under development for maritime shipping at the IMO. To date, efforts to meet discharge standards have generally increased the energy required for ballast management. New approaches should attempt to reverse this trend. Recent management efforts have significantly reduced the actual volume of discharged ballast water, and in some cases eliminated discharges in all routine operations. Such direct approaches should continue to be developed, and regulatory, monitoring, and enforcement efforts should recognize the real reduction in environmental impact from these practices. As these are not technology-based approaches, however, they are not further reviewed here.

Finally, meeting more stringent standards will require consideration of: efficacy of mechanical separation and disinfection technology; in-tank monitoring, treatment, and mixing; and controls to avoid contamination from sources such as adjacent tanks, piping systems, and debris or fluids falling into tank accesses. These three considerations are elaborated upon in the following subsections.

>>Efficacy of mechanical separation and disinfection technology

Meeting more stringent standards will require large improvements in mechanical separation and disinfection technology. Application considerations include:

Handling the heterogeneity or "patchiness" of water on uptake and treated water on discharge.

- For example, treated ballast water at the bottom of a tank may have a high sediment load. When stripping these tanks, sediment particles would reduce the efficacy of a UV system designed to operate on discharge.
- Providing a positive, or fail-safe, barrier to the release of untreated ballast water. With the proposed Phase 2 standard requiring "seven-nines," this implies 100% efficacy with only 3.15 seconds of interrupted service per year of operation. [Equation 4]

$Down\ Time = Duration - (Reliability \times Duration)$ [Equation 4]

$Down\ Time = (Duration\ (years) - \big(Reliability\ (percentage) \times Duration\ (years) =$

$(1\ year - 99.99999\% \times 1\ year \times (3.15E07 seconds year) = \quad 3.15\ seconds$ [Equation 4]

>>In-tank monitoring, treatment, and mixing

Meeting more stringent standards will require careful monitoring of in-tank conditions. This becomes particularly important when: hold times are very long and surviving organisms may reproduce; hold times are very short and treatment processes may not have adequate time to take effect; sediment loads provide a protective layer for organisms from the disinfection process; "patchiness" in the uptake challenge water overwhelms the treatment process during ballast-water uptake. Application considerations include:

- Means to monitor tank conditions. This is particularly challenging because typical ballast-water tanks are complex, and are known to have hydrodynamic "dead zones" not flushed out in a typical ballast cycle.
- Means to treat a full ballast-water tank. A full tank may require treatment, or re-treatment, for numerous reasons including: ineffectiveness of the uptake process; contamination from external sources; and exceedance of expected hold time duration.
- Means to mix a full ballast-water tank. An ideal mixing system would suspend sediment loads, preclude untreated pockets of ballast water, permit representative monitoring of the tank, and provide a means of evenly treating a tank's contents.

>>Controls to avoid contamination

Contamination is always of concern, especially so when considering more stringent standards. Application considerations for avoiding contamination include:

- Isolating the ballast-piping system. Many present-day ships have a cross-over to fire mains, black and grey water drains, bilge water lines, and cooling-water circuits.
- Maintaining a high level of tank structure integrity. Especially in aging vessels, decrepit tank structures can permit transfer of fluids from adjacent tanks, piping systems running through the tanks, fluids pooling on tank tops and directly from ambient water through seams or pipe fittings in the vessel's side shell.
- Protecting tank vents. Ballast-tank vents are typically fitted with only a rough screen or a ball check device to minimize seawater entry. Given more stringent standards, protecting vents from seawater or "bug" entry is of increased importance.

<u>Identifying Key Elements of an Idealized Shore-Side Plant for Treating Ballast Water</u>

In developing new approaches to treating ballast water, the wastewater-treatment industry is an obvious place to turn. This industry has developed methods to disinfect large volumes of water to very high standards for large and small organisms. New approaches adapted from that arena may be very efficacious and achieve the desired more stringent standards, but will take time to develop, trial, and determine their practicality and cost impacts. Nonetheless, it is useful, at least as a thought exercise, to consider a shore-based treatment system as an idealized solution. Its operational particulars will form the basis of comparison for the following subsection, which considers new approaches to ballast-water treatment on board a marine vessel.

To that end, we developed a hypothetical design for an onshore ballast-water treatment plant with a design capacity of 20,000 m^3 of ballast water per day. This is equivalent to ~800 m^3 per hour, roughly similar to a "low ballast dependent" vessel such as a containership. ("High ballast dependent" vessels, such as Great Lakes bulkers and large tank ships, would require a treatment plant 5 to 12 times larger.) The design requirements for this hypothetical treatment plant were estimated as:

- Equalization tanks of volume 20,000 m^3.
- Plain sedimentation area of ~1,000 m^2.
- Granular media filtration of ~120 m^2.
- Three UV units each at ~800 m^3 per hour.
- Sludge and backwash handling.
- Possibly to include a membrane-filtration unit.

The committee is confident that systems of this type can meet IMO D2, and indeed, D2 X 1000 standards for all size fractions, including the IMO-specified bacteria; however, a limited program of pilot scale testing is recommended to confirm optimum design parameters. Such pilot testing programs are common practice in water and wastewater treatment plant design.

<u>Concepts for Meeting a More Stringent Ballast-Water Treatment Standard</u>

This section envisages conceptual systems whereby both ballast-water management and treatment technologies can meet more stringent standards. These conceptual systems have been developed with reference to challenges outlined in previous subsections, provide an understanding of the technical and operational demands of those challenges, and have the goal of approaching the efficacy of the above-mentioned, idealized, onshore treatment plant. These approaches will significantly increase the operational burden on ship operators, but are technically feasible to integrate into new vessel designs. Integrating these conceptual systems into existing vessels will be challenging on most, and not possible on many. Finally, these conceptual systems and processes need better definition to develop cost-benefit analyses; neither capital nor operating costs have been estimated.

>>Overview

Here we consider one example of a conceptual approach to a new design (Figure 4.1). This approach will demand at least 3 to 4 times the number of components, effort, space, and expense of existing approaches to BWMS. Treatment integration is based on utilizing large media filters that are integral to the vessel hull on ballast water uptake and discharge and the ability to re-circulate the ballast water in the ballast water tanks, in order to dose, monitor and maintain oxidant levels in the ballast water tanks. For ballast water discharge a residence tank is considered to ensure neutralization of the oxidant, and a final UV disinfection step through a dedicated ballast water discharge connection. The concept considers volumes for a Panamax container ship, with a ballast volume of 17,000 cubic meters and a discharge rate of 500 cubic meters per hour.

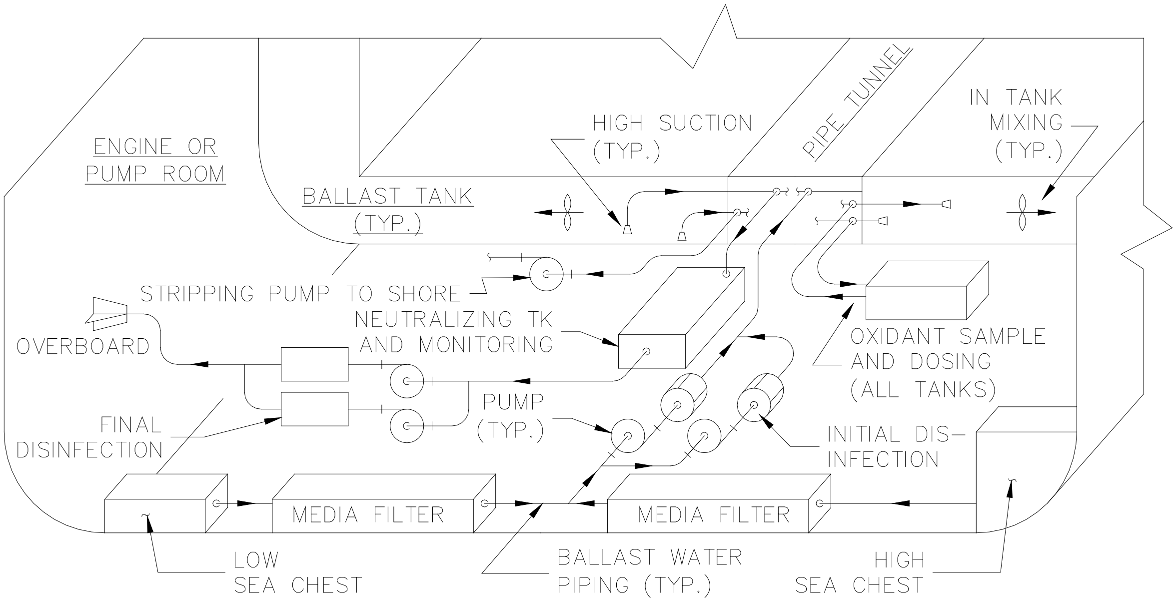


Figure 4.1. – Concept Sketch of New Approach to Ballast Water Treatment

>>Ballast water uptake

Two traditional, but oversized, seachests (intake structures for ballast water in ships' hulls) would serve to take up ballast water. Piping will generally be 300 mm nominal. Each would include standard skin-valve isolation and piping materials. The seachests would be located port and starboard, one high and one low, with a cross-over suction main connecting each. This provides flexibility for avoiding sediment when the ship is close to the bottom, and algal blooms when the ship is light and the high seachest is close to the surface. We appreciate that seachests can be points of refuge for nonindigenous species, but do not consider here methods for keeping them and adjacent hull areas free of fouling organisms; such considerations were outside our mandate.

The cross-over suction main would discharge by gravity into two large media chambers plumbed in parallel and each sized for full flow. This arrangement allows one to be by-passed during back-flush cycles. Each would be built into a one-meter height double bottom in the ship's hull and eight-meters square for a volume of 64 cubic meters each. Industrial waste water industry media with tolerance for velocities approaching 60 meters per hour, and a useful life of six years between dry dock periods would be considered. Six-year servicing of media would be through manhole covers.

Ballast water leaving the media filter is disinfected prior to entering the ballast water tanks, either by a UV or an oxidant chemical. This transfer is possible by using ballast water pumps, or through gravity when there is adequate head pressure from the sea. The piping would be direct, through a pipe tunnel for ease of monitoring condition and servicing, and have no cross-connects.

>>In tank
Once a ballast water tank is full or partially full, it would be periodically mixed through the use of low pressure – high volume air bubbles, or in tank eductors. This mixing will allow the application of an oxidant to a prescribed level, and the monitoring and the maintenance of that oxidant level. Mixing frequency would be based on detected oxidant decay levels, as well as calculations to prevent sediment from settling.

The tanks would be fitted with pressure-vacuum relief valves that only open when the ballast water is being transferred or occasionally to relieve built-up pressure or vacuum from a diurnal cycle. The gauging system would be a closed system to limit contaminants from entering the tanks. At least two tank vents would be installed. Each vent would be fitted for ready connection to ventilation blowers to facilitate gas freeing tanks to make safe for personnel entry. Depending on the required oxidant level, the ballast tanks may require a special coating system. In addition, piping system gaskets and valve seals may require special materials not typically used in seawater applications.

>>Discharge
Each tank would be fitted with piping for deballasting with a high suction at approximately 300 mm above the tank bottom, and a low suction at approximately 75 mm above the tank bottom. The high suction would be used for ballast tank discharge, such that the discharge does not contain sediment. The low suction would be used for stripping sediment from tanks when suitable disposal facilities are available.

The discharge piping would be independent from the uptake piping. Each tank would be outfitted with an isolation valve connecting it to the discharge main header. The header would lead to a reactor tank of one-meter height built into the ship's double bottom with at least twenty-five m^3 capacity allowing a contact time of at least three minutes. During the contact time, the oxidant level would be neutralized and water quality confirmed prior to discharge. The system would be fail safe, returning the ballast water to the ballast water storage tank if needed.

A dedicated seawater overboard, designed to avoid contamination from ballast-water uptake or other sources, would be fitted for discharging the ballast water. As close as practical to the overboard, a final UV disinfection step would be considered. This final disinfection step would provide assurance against contaminants in the reactor tank where the oxidant was neutralized, as well as providing a measure of caution in treating the ballast water a second time by a different process.

The ballast water may be moved through the discharge by gravity if there is adequate head in the ballast tank. At any time, a pump would take suction on the reactor tank, avoiding pump contact with the oxidants. The pump would then discharge to the UV unit and overboard.

>>Summary
The above arrangement is presented as a conceptual system for meeting more stringent standards through higher filtration levels, greater control of oxidant levels in tanks, and a final disinfection using UV radiation. This conceptual process has not undergone any biological efficacy testing

or toxicity analysis. It is presented solely to assist in the evaluation of how more stringent treatment standards might impact vessel arrangements, operations, and costs.

5.2. Charge Question 3b. Part a

What are the principal technological constraints or other impediments to the development of ballast water treatment technologies for use onboard vessels to reliably meet any or all of the discharge standards presented in Table 1 of the White Paper and what recommendations does the SAB have for addressing these impediments/constraints?

Response:

The performance of ballast-water treatment technologies and associated management processes is a product of a marine vessel's characteristics and the quality of water it ballasts. The vessel characteristics of primary concern are the rate and volume of ballast-water uptake, holding time, and the rate of ballast-water discharge. These characteristics are fundamental to the safe operation of the ship, serve to maintain stability and trim during cargo movements, manage propeller submergence and navigation-bridge sight lines while transiting, and account for fuel consumption. The maximum capacity of these characteristics varies widely among vessel types, as is captured in Table 4.1. Variations within each vessel's maximum capacities are significant, e.g., partial discharge of ballast tanks is a common practice.

The quality of water ballast will vary significantly in its temperature, salinity, and turbidity, as well as in the concentration and composition of its entrained organisms Test facilities have generally conducted testing under specific "challenge water" conditions, e.g., see Text Box 4.1. These challenge-water conditions are intended to tax the technology, yet lie within the realm of natural conditions where marine vessels operate.

We list below principal constraints and impediments:

- Shipboard ballast-water treatment technologies are developing rapidly. The focus to date has been on engineering the technology. Less consideration has been given to the following, which are equally important: training; operation; maintenance and repair; and monitoring effectiveness. Further, the focus on the efficacy of the treatment device has been at the expense of ensuring integration with vessel mechanical systems and marine operational activities.

- With regard to monitoring effectiveness, achieving zero live organisms in the discharge is an unrealistic and unattainable goal. The complexity of the systems and the difficulties associated with counting live organisms, particularly the smaller size classes, combine to limit our ability to measure improvements to levels 100X and 1000X IMO.

- Facilities at which technologies may be tested are few and there is a strong need to increase sharing of data and specific protocols among them. On a positive note, sharing of among these facilities occurs within the US and is also underway internationally. In the US, the three testing facilities, Maritime Environmental Resource Center (MERC, University of Maryland, Great Ships Initiative (Superior, WI), and Golden Bear (California Maritime Academy) use EPA's ETV protocols and work closely on standardization. Internationally, efforts to develop testing technologies are being made through the IMO Globallast program and the EC funded Northsea Ballast Water Project. In addition there are independent collaborations between test facilities such as MERC and Korean Ocean Research and Development Institute (KORDI, South Korea), but these efforts are only in early stages of discussion and planning.

- There is no established compliance, monitoring, and enforcement regime which will focus development of future technologies. To our knowledge, none are available.
-
- There is disagreement on discharge standards; they vary domestically, i.e., from state to state within the USA, and internationally.

Despite the constraints listed above, we note that successful systems will, as described by Glosten– Herbert – Hyde (2002):

1) meet the demands of the shipboard marine environment;
2) minimize operational changes to the vessel's existing ballast management systems;
3) fit within the normal and existing operational procedures of shipboard personnel;
4) minimize initial capital and life-cycle costs; and
5) meet the existing safety standards of the industry, regulatory bodies and the target vessel operating company.

In the context of recommendations, we expand briefly on these five points:

- The shipboard marine environment is corrosive and characterized by vibrations and ship motions. One should not assume shore-side systems can transfer straightforwardly to ships. Shipboard service history will be important in selecting system components. Even so, the characteristics of water in some shipboard applications may differ from those of ballast water, e.g., the amount of sediment in ballast water may be greater, thus prediction of system performance based on service history may be challenging.

- Vessels are initially designed with ballasting capabilities and procedures that match their intended service and voyage profile. In retrofitting vessels for ballast-water treatment, the system(s) employed ideally will fit within those original parameters and minimize disruption.

- Ships' crews are small in number and busy; therefore, any new system must be easy to operate, maintain, and ideally be remote controlled from the ballast-control console. It is also desirable to have automated operation of the system in or near port, typically a busy time for personnel. And in the same vein, durability and ease of maintenance are requisites.

- A treatment system's full cost includes not only its initial purchase and installation costs, but its operational costs over the long term as well. System reliability, durability, cost of spares, and ease of maintenance, e.g., filter element or bulb replacement, all contribute to the desired minimization of these long-term costs.

- Most importantly, the treatment system should pose no unreasonable health risk for the crew, not create a higher risk for vessel safety, and require no exception to the vessel owner's safety procedures. The equipment installation and operation procedures must also meet Classification Society, Flag State, and Port State control authorities' requirements.

Finally, Subgroup 2 makes the overall recommendation that shipboard constraints to ballast-water treatment technology need to be considered relative to potential increased usage of shore-based treatment facilities (see also response to Charge Question 4).

5.3. <u>Charge Question 3b. Part b.</u>

Are these impediments more significant for certain size classes or types of organisms (e.g., zooplankton versus viruses)?

Can currently available treatment processes reliably achieve sterilization (no living organisms or viable viruses) of ballast water onboard vessels or, at a minimum, achieve zero or near zero discharge for certain organism size classes or types?

Response: Shipboard impediments apply to all size classes of organisms and indicator microbes. Existing systems, or combinations of systems, are capable of removing (e.g., mechanical separation) or killing (e.g., deoxygenation, UV, chlorine dioxide) nearly all organisms > 50 µm in minimum dimension. Following that general statement, however, we know filtration is most effective with larger organisms such as zooplankton, UV irradiation kills or inactivates unicellular organisms and viruses more efficiently than it does metazoans, and deoxygenation will not eliminate bacteria and in fact, may result in their increased abundance. Pragmatically, it may be best to focus on eliminating larger organisms in ballast water as completely as reasonably possible, then assessing the extent to which smaller organisms (e.g., bacteria, viruses) survive the treatment and direct reasonable resources to reduce their numbers.

If ballast water were sterile, it would be "free from living organisms and viruses" (Madigan and Martinko, 2006). Given the volumes of water involved, we believe that onboard sterilization of ballast water is not reasonably possible given current or foreseeable technologies. There simply is not enough energy on a ship to implement steam autoclaving. Reliable operation of complex processes by those with limited training is problematic in the absence of a strong quality assurance (QA) program. Further, as a practical matter, the assurance of sterilization is impossible to verify if the methodology for collecting organisms and assessing their viability is variable or uncertain (these issues are considered in response to Charge Question 4).

Charge Question 3b. continues: "*If not sterilization, then is it possible to achieve zero or near-zero discharge for certain organism size classes or types?*" As indicated above, we believe the technology exists to remove nearly all organisms ≥50 µm (minimum dimension) from discharged water. Whether that degree of removal could be proved through measurements (quantitative sampling for statistical verification), especially at full-scale testing or operation, is another issue. Subgroup 7 (Cross-cutting group on statistics) has considered the limits of detection and concluded there is no assurance of zero or near-zero discharge. Our subgroup concurs. Such a value is not measureable in a scientifically defensible way and instead represents a social preference. No one in the fields of toxicology or waste-water treatment, disciplines represented within our subgroup, believes that such a goal is realistically achievable in the real world; it is an unreasonable requirement and should be reconsidered as a ballast-water treatment standard. The problems with zero or near-zero discharge amplify when smaller organisms are considered, those <50 µm in shortest dimension, e.g., phytoplankton, bacteria, and viruses.

Finally, while “zero or near zero discharge” may theoretically be achievable (and arguably even measurable) at a test facility, it will never be obtained or verified at “end of pipe” for a working ship. The water in the tank might be “clean”, but it will flow through piping that will not be clean. Particularly with non-biocide units, we anticipate there will always be pipe dead ends, crosses, etc., where organisms can find refuge, then emerge and be detected during testing. We have named this the paradox of "perfect systems on imperfect ships".

The current filter and disinfect approach may not be adequate to meet more stringent standards. Treatment processes will need to become multistage and part of an integrated ballast water management effort (see response to Charge Question 4). Meeting increasingly stringent performance standards will require that BWT systems perform nearly perfectly, nearly all of the time. Existing ship ballast water management systems and practices do not support this level of control or performance; a fundamental shift in system design and operational practices would be needed.

Reliability is a key metric that is not captured in the current certification-focused testing regime. A well defined compliance, monitoring, and enforcement regime is required so that system engineers can target those metrics, rather than be focused primarily on a certification test.

6. RESPONSE TO CHARGE QUESTION 4: LIMITATIONS OF EXISTING STUDIES AND REPORTS

6.1. Charge from EPA

This section responds to Charge Question 4: "What are the principal limitations of the available studies and reports on the status of ballast water treatment technology and system performance and how can these limitations be overcome or corrected in future assessments of the availability of technology for treating ballast water onboard vessels?" Bearing in mind the broader charge to "provide advice on technologies and systems to minimize the impacts of invasive species in vessel ballast water discharge" (Feb. 2010 Federal Register notice), we address aspects of ballast water discharge not covered in the responses to earlier charge questions. Specifically, in later parts of this section, we address limitations of technology and systems to enable effective compliance and enforcement, and explore alternative approaches to ballast water management including risk-based approaches (e.g., Hazard Analysis and Critical Control Points, HACCP) as well as land-based facilities for ballast water treatment.

6.2. Testing shipboard treatment systems: Protocols, analysis, and reporting practices that could be improved

6.2.1. Confusion of research & development and certification testing

Currently little if any distinction is made between research and development testing and certification testing. Adjustments to BWMS are made during testing of prototypes, and the most favorable results are reported to gain certification approval. Assembly line-produced BWMS are not often tested. Thus certification may be gained on the basis of unrealistically favorable results that may not be representative of replicated testing with multiple commercially available units of a BWMS. EPA/USCG should mandate that R&D testing be barred from use in certification testing.

To ensure that the performance of ballast water treatment systems is objectively and thoroughly evaluated during certification testing, experienced specialists in an independent testing organization should conduct the tests, rather than the system manufacturers. This is important because science has shown that it is extremely difficult, after the creator of a system has been constructively designing it, to change h/her perspective and instead approach the treatment system from a "deconstructive" state of mind to form the necessary mental attitude of wanting to find flaws and expose weaknesses and limitations (Myers 1979). Thus, verification testing conducted by independent specialists is critical in accomplishing a scientifically rigorous assessment of system performance. The testing organization should provide detailed information about the expertise of its personnel, and the established credentials of these personnel should be approved by the U.S. EPA/USCG. Certification testing should be conducted by a party independent from the manufacturer with appropriate, established credentials, approved by EPA/USCG.

6.2.2. Lack of standardized testing protocols

Comparison of the performance of different ballast water treatment technologies requires consistent testing protocols (Phillips 2006, Ruiz et al. 2006). Except for the ETV protocol (U.S. EPA 2010), which is in final clearance, there is no comprehensive international, federal or state program that includes performance standards, guidelines, and protocols to verify treatment technology performance, and no standardized sets of methods for sampling and analysis of ballast water to assess compliance. The existing federal and various state standards lack consistency as well. Treatment evaluations generally are designed to test whether a given technology can meet International Maritime Organization (IMO) D2 standards in accordance with both the IMO Guidelines for Approval of Ballast Water Management Systems (G8) and the Procedure for Approval of Ballast Water Systems that Make Use of Active Substances (G9) (IMO 2008a,b).

With exception of the U.S. Coast Guard's (USCG's) Shipboard Technology Evaluation Program (STEP), BWMSs presently are not approved for use in compliance with federal ballast water management requirements. Thus, while there are various state ballast water management requirements, there is no formal environmental assessment approval program for BWMSs at the federal level. US EPA has, however, included provisions in the draft NPDES Vessel General Permit for ships with treatment systems that discharge ballast water containing biocides or chemical residues. In addition, US EPA's Environmental Technology Verification (ETV) Program was created to accelerate the development and marketing of environmental technologies including ballast water treatment, and recently developed a treatment technology verification protocol that is available in draft form (U.S. EPA 2010). Protocols in the IMO G-8 Guidelines, supported by the new, approved U.S. EPA Environmental Technology Verification (ETV) Program (U.S. EPA 2010), specify taking whole-water samples of at least 1 m3 (1,000 L) for organisms > 50 µm, and at least 1 m3 for organisms 10 µm - 50 µm. The state of California also has developed "Ballast Water Treatment Technology Testing Guidelines" that are intended to provide a standardized approach for evaluating treatment system performance (Dobroski et al. 2009). Procedures are being developed for verifying vessel compliance with performance standards as well.

Performance standards set requirements for technology to achieve and should help to advance progress in treatment system designs, but only if a set of standardized, practical, scientifically rigorous assessment techniques is available to evaluate treatment system performance. The IMO standards are based upon different size groups of organisms, and all size groupings offer challenges in efforts to assess performance (see below). Assessment has relied upon a subset or "surrogate" group of organisms as representative of treatment of all bacteria (see Section 2. C, below). There is as yet no strong evidence for suitable proxy organisms to represent the virus size class, and no acceptable methods for verification of compliance with a total virus standard.

The following analysis summarizes the ETV recommendations, but focuses on differences between this committee's recommendations and the recently developed ETV protocols (U.S. EPA 2010). Both the ETV protocols and the committee's recommendations feature land-based rather than shipboard testing to provide comparable conditions for verifying treatment performance by independent testing operations.

A) Test Verification Factors

All treatment systems should be verified considering the following factors: biological treatment efficacy, operation and maintenance (OM), reliability as measured by the mean time between failure (MTBF), cost factors, environmental acceptability including residual toxicity, and safety. ETV and the committee agree that biological treatment efficiency (the removal, inactivation, or death of organisms) should be measured as the concentration, in the treated ballast water discharge, of the organism size classes indicated in the IMO standard, comparing the untreated versus treated ballast water. Other measurements can include organism removal efficiency (the percentage reduction of organisms that were present in the untreated ballast water), and water quality parameters in comparison to appropriate water quality standards. Verification protocols should include detailed descriptions of on-site sampling, sample handling (chain of custody), in-place mechanisms for selecting independent laboratories with appropriate expertise and certification to conduct the sample analyses, and requirements for compliance reporting.

The ETV and the committee agree that tests and species selected for toxicity testing during commissioning need to be carefully justified and protocols detailed in the Test Plan. BWMSs that involve a chemical mode of action are regulated under the National Pollutant Discharge Elimination System (NPDES) permit process (Albert et al. 2010), which requires demonstration of "no adverse effects" as evaluated through chemical-specific parameters and standardized Whole Effluent Toxicity (WET) testing (U.S. EPA 2002a-c; 40 CFR 136.3, Table 1A). WET experiments are designed to assess the effects of any residual toxicity on beneficial organisms in receiving waters. Standardized acute and chronic toxicity assays have been developed by the U.S. EPA for a limited number of freshwater and marine species (Table 6.1). The ETV did not comment on the freshwater assays, but recommended that toxicity tests for biocide treatments in brackish and marine waters should include the U.S. EPA acute toxicity assay for mysids (EPA OPPTS Method 850.1035; http://www.epa.gov/opptsfrs/OPPTS_Harmonized/850_Ecological_Effects_Test_Guidelines/Drafts/850-1035.pdf , and the chronic toxicity assays for the inland silverside Menidia beryllina (larval survival and growth, EPA Method 1006.0; http://www.epa.gov /OST/WET/disk1/ ctm13.pdf) and the sea urchin, Arbacia punctulata (fertilization, EPA Method 1008.0; http://www.epa.gov/OST/WET/disk1/ctm15.pdf)). The committee recommends that freshwater assays also be included in toxicity testing.

Complete results including failures should be reported as standard practice. These data are needed to enable realistic evaluation of a given BWMS. At present, there is no requirement under IMO to report tests in which a treatment system fails. Rather, for type testing success, a system must report only a specified number of successful tests. The committee strongly recommends that reports should include all failed and successful tests, and that criteria for approval should consider the failure rate (proportion of tests that were successful).

Table 6.1. Freshwater and marine species for which the U.S. EPA has developed standardized acute and chronic toxicity assays (http://www.epa.gov/waterscience/WET).

Habitat	Acute Toxicity	Chronic Toxicity
Freshwaters		
Algae	---	*Selenastrum capricornutum* (growth)
Zooplankton	*Ceriodaphnia dubia*	Survival, reproduction
	Daphnia magna	---
	Daphnia puplex	---
Fish	Bannerfin shiner (*Cyprinellale edsi*)	---
	Brook trout (*Salvelinus fontinalis*)	---
	Fathead minnow (*Pimephale spromelas*)	Larval survival, growth; embryo-larval survival, teratogenicity
	Rainbow trout (*Oncorhynchus mykiss*)	---
Marine		
Mysid shrimp	*Americamysis bahia*	Survival, growth, fecundity
Sea urchin	---	*Arbacia punctulata* - fertilization
Fish	Sheepshead minnow (*Cyprinodon variegatus*)	Larval survival, growth; embryo-larval survival, teratogenicity
	Silversides (*Menidia beryllina, M. menidia, M. peninsulae*)	*M. beryllina* - larval survival, growth

B) Challenge Conditions

The committee recommends that testing should be applied across the full gradient of environmental conditions (temperatures, salinities) represented by the Earth's ports. All treatment technologies should function well across the range of physical/chemical conditions and densities/types of biological organisms that a ship encounters. Thus, BWMSs should be verified using a set of standard challenge conditions that ideally encompass the suite of water quality conditions which captures the full gradient of environmental conditions represented by major ports, and the range of densities of the organisms and organism size classes.

The ETV states that the objectives for challenge conditions are to verify treatment system performance using a set of "challenging, but not rare, water quality conditions representative of the natural environment;" and to verify removal or kill of organisms ranging in size from bacteria to zooplankton, using natural assemblages and appropriate analytical techniques that enable quantification of densities of live organisms (U.S. EPA 2010, p.18). It is important to evaluate the effectiveness of treatment systems under conditions that challenge the technology because certain water quality conditions can interfere with some treatment processes. These physical/chemical environmental conditions are generally understood and relatively few in number, which helps to limit the number of water quality metrics that must be included in the protocol (Table 6.2).

Table 6.2. Comparison of the ETV's recommendations (U.S. EPA 2010) and the committee's recommendations, considering minimum criteria for challenge water total living populations, criteria for a valid BE test cycle (living organisms in control tank discharge after a holding time of 1 day), and water types (salinity groupings) for completion of BE tests.[1]

Minimum Criteria for Challenge Water Total Living Populations; and
Criteria for a Valid BE Test Cycle - Living Organisms in Control Tank Discharge After 1 Day Holding Time

Size Category[2]	ETV	This committee
≥ 50 µm	10^5 organisms m^{-3}, 5 species in 3 phyla	same
≥ 10 µm and < 50 µm	10^3 organisms mL^{-1}, 5 species in 3 phyla	same
Other[3]	< 10 µm: 5 x 10^2 mL^{-1} as culturable aerobic heterotrophic bacteria	< 10 µm: 10^3 selected protists mL^{-1} < 2 µm: same as ETV for < 10 µm
Water Types (Salinity Groupings) for Completion of BE Tests[3]		
Fresh (salinity < 1)	All three salinity ranges;	All three salinity ranges;
Brackish	brackish ≡ salinity 10-20;	brackish ≡ salinity 1 to < 28
Marine	marine ≡ salinity 28-36	marine ≡ salinity > 28
Physical/Chemical		
Environmental:	Temperature (4-35°C), DOC, POC, TSS, MM, pH, DO	
Others of Specific Interest:	Example - nutrient concentrations (TN, TP, TKN, NH_x, NO_x, SRP)	

[1] Abbreviations: DOC, dissolved organic carbon; POC, particulate organic carbon; TSS, total suspended solids = particulate organic matter (POM) + MM (mineral matter); DO, dissolved oxygen; TN, total nitrogen; TP, total phosphorus; TKN, total Kjeldahl nitrogen; NH_x, ammonia + ammonium; NO_x, nitrate + nitrite; SRP, soluble reactive phosphorus.

[2] Size ≡ maximum dimension on the smallest axis.

[3] Effects on culturable aerobic heterotrophic bacteria are assumed to be indicative of effects on all bacteria.

[4] The ETV' water quality challenge matrix for verification testing includes the following minimum water characteristics for the three salinity water types as: Fresh (salinity < 1), dissolved organic matter, 6 mg L^{-1} as DOC, and particulate organic matter, 4 mg L^{-1} as POC; brackish (salinity 10-20), MM 20 mg L^{-1} and TSS 24 mg L^{-1}; and marine (salinity 28-36), temperature (full range), 4-35°C.

In recognition of the difficulties that can be encountered, especially in ship-based testing, tests of the three salinity ranges could include two land-based tests and one ship-based test. Our rationale for recommending tests of all three salinity ranges is that if a given BWMS is planned for use across the salinity gradient, but testing indicates that its efficiency at organism removal is poor under one or more of the salinity groupings, then that system should not be used by ships visiting ports that are characterized by such conditions. Similarly, if a BWMS is planned for use across other environmental gradients (e.g. temperatures from cold to warm waters), but tests indicate that it has poor efficiency in removing biota under part of the natural temperature range, then that system should not be used by ships visiting ports that have such conditions. A fully crossed design should be used where possible, for example, if natural water can be obtained at the desired salinity range. As another example, cold temperatures may be ideal, but for practical reasons most tests must focus on the challenge threshold temperature of available organisms.

There are major practical constraints on such tests. First, alterations to establish the natural range of physical/chemical conditions should be imposed without affecting the concentrations, diversity, and viability of the biota present. For that reason, natural water sources ideally should be used to impose the levels of salinity, rather than artificially modified salinity. Artifactual interactions may occur between biota and artificial media, for example, artificial seawater prepared with commercially available “sea salts.” The committee thus diverges from Anderson et al. (2008) in recommending that a source of filtered, high-quality natural freshwater or seawater should be used to prepare treatments insofar as possible. There are pros and cons with either approach: Artificial sea salts are expensive but enable routine preparation of media. However, caution is warranted in using artificial sea salts because some ingredients that are not found in natural seawater, such as phthalate esters (e.g. di(2-ethylhexyl)phthalate, a commonly used plasticizer in Instant Ocean aquarium salts), are abundant and can be toxic to aquatic life, resulting in spurious data (e.g. Peal 1975, Moeller et al. 2001). Various dissolved organic compounds that are important to the nutrition and the life histories of aquatic organisms (see Burkholder et al. 2008) likely will be missing from artificially constructed media. While use of natural waters avoids such problems, the natural water source should be as free as possible from toxic pollutants, which are increasingly ubiquitous in fresh, brackish, and coastal marine waters (Kay 1985, Pate et al. 1992, Loganathan and Kannan 1994, Hoff et al.1996, U.S. EPA 2000, Shaw and Kurunthachalam 2009), or contain at most only trace levels of such pollutants. Final selection of natural versus an artificial water sources requires careful consideration of these issues. In addition, when using artificial water sources or otherwise modifying environmental conditions, timing is important: Care should be taken to avoid imposing rapid environmental changes that, alone, could stress or kill the biota tested.

The ETV recommends adjusting POM by adding commercially available humic materials, plankton, detritus, or ground seaweed; commercially available clays can be added to adjust the mineral matter concentration (U.S. EPA 2010). However, the committee is concerned that the cation exchange capacity of the dried, then rehydrated clays can significantly alter plankton communities (Avnimelech et al. 1982, Burkholder 1992, Cuker and Hudson 1992). Artificial modification of DOC is difficult to achieve without a strong potential of affecting the biota present, especially the smaller size-fraction components. The committee believes that the testing organization should be required to verify, insofar as possible, that in preparing the test water, any materials added had minimal effects on the biota, and "minimal effects" should be clearly defined.

The IMO (2008a,b), the ETV (U.S. EPA 2010), and other suggested standards (e.g. California VGP 401 certification/State regulations (see Albert et al. 2010) make no mention of protists in the < 10 µm size range. Many harmful organisms occur in this size range (e.g. harmful "brown tide" pelagophytes Aureococcus and Aureoumbra, many harmful cyanobacteria, certain potentially toxic dinoflagellates etc. - see Burkholder 1998, 2009). The selected bacteria presently targeted for standards are not useful as indicators for the presence of these taxa which, as a general grouping, can adversely affect both environmental and human health (Burkholder 1998, 2009). Thus, failure to consider this size class represents a serious omission in efforts to protect U.S. coastal estuarine/marine waters and the Great Lakes from harmful species introductions. For some of these taxa, such as toxigenic Microcystis spp. affecting some of the Great Lakes (e.g., Boyer 2007), the tendency of the cells to aggregate into colonies can sometimes "boost" them into the > 10 µm size range, but for others such as brown tide organisms, such aggregation does not occur .

There is a critical need to include harmful representative protists (which should be expected to vary depending on the geographic region) from this size class in developing protective ballast water standards. Depending on the salinity and the region, and based on the smallest cell dimension, examples of candidates could include selected toxigenic cyanobacteria such as Anabaena flos-aquae, the haptophyte Prymnesium parvum, brown tide organisms Aureococcus anaphogefferens or Aureoumbra lagunensis, small toxigenic dinoflagellates such as Karlodinium veneficum, and the pathogenic protozoans Giardia spp. and Cryptosporidium parvum that are found across the salinity gradient. Accordingly, protists in this size class should be included in standards for assessing the performance of BWMSs.

C) Verification Testing

The committee differs from the ETV on some protocols, including specifics for collecting water quality and biological samples in performance testing of BWMSs (Table 6.4). For zooplankton, phytoplankton and other protists, the commitee supports the need for collecting at least 3-6 m3 of sample volume at each required location on a time-averaged basis over the testing period. Field quality control samples and field blanks should be taken under actual field conditions to provide information on the potential for bias from problems with sample collection, processing, shipping, and analysis (Ruiz et al. 2006). Accepted scientific methods should be used for all analyses (e.g. for water quality parameters, U.S. EPA 1993, 1997; American Public Health Association (APHA) et al. 2008). Biological samples should be collected from the time-integrated sample volumes during the test cycle; sample collection tanks should be thoroughly mixed prior to sampling to ensure homogeneity. Samples collected from control and treated tank discharges should be taken upstream from pumps or other apparati that could cause mortality or other alterations. Note that analysis of some parameters is extremely time-sensitive (Table 6.4). For example, zooplankton die-off occurs in samples held for 6 hours or more. The approximate maximum hold times should maintain detectable zooplankton mortality over time at < 5%.

Table 6.4. Sample volumes, containers, and processing for core parameters and auxiliary nutrients (nitrogen, N; phosphorus, P; silicate, Si; carbon, C). Note that HDPE ≡ high-density polyethylene, and POC information is from Baldino (1995). Recommendations that differ from those in the ETV (U.S. EPA 2010) are indicated in **bold**.[1]

Parameter	Minimum Sample Volume	Containers	Processing/Preservation Holding Time	Maximum
TSS	100 mL	HDPE or glass	Process immediately or store at 4^{o}C	1 week
DOC	25 mL	glass	Pre-combusted GF/F filters; **preserve filtrate with H_3PO_4 (pH < 2), hold at 4^{o} in darkness (APHA et al. 2008)**	28 days
POC	500 mL	HDPE	Filter (GF/F in foil); freeze filter	28 days until analysis
MM	= TSS - POC	----	----	----
DO	300 mL **or *in situ* sensor**	glass BOD bottles	Fix (Oudot et al. 1988); titrate in 2-24 hours; or Continuously recording	24 hours
Chlorophyll *a*,[1] pheopigments	400 mL	dark HDPE	Filter (GF/F); fix with saturated $MgCO_3$ solution; freeze filter until analysis	3 weeks
Phytoplankton No.[2] (viable, < 10 µm - selected harmful taxa)	**500 mL**	**dark HDPE**	**Filter (Nuclepore or Anotech); assess autofluorescence (e.g. MacIsaac and Stockner 1993), <u>or</u> Filter, fix (e.g. 0.2% (v/v) formalin), freeze filter; <u>or</u> filter, fix, followed by selected molecular techniques (e.g. Karlson et al. 2010)**	**process immediately 3-4 weeks months**

Table 6.4, cont'd.

Parameter	Minimum Sample Volume	Containers	Processing/Preservation Holding Time	Maximum
Phytoplankton No. (viable, nano-/ micro-plankton, ≥ 10 to 50 µm **and ≥ 50 µm)** [3]	3 m^3 (1,000 L) → 1 L	60 mL dark HDPE	Viable: No preservative; stain with FDA, CMFDA; **or, fix with acidic Lugol's solution (Vollenweider 1974), store at 4°C in darkness, and quantify as viable when collected and combine with various molecular techniques to confirm harmful taxa of interest (e.g. Karlson et al. 2010)**	process immediately; **or 28 days, preferably 1 week**
Other protists (#) [1] **(viable heterotrophs, < 10 µm - selected harmful taxa)**	**500 mL**	**100 mL, dark HDPE**	**Techniques appropriate for the selected taxa (e.g. U.A. EPA 2005)**	**variable**
Zooplankton # (viable, ≥ 50 µm)	3 m^3 (3,000 L) [4] → 1 L	1-L flask	No preservative; subsample 450 1-mL wells[3] and probe; **fix with buffered formalin and Rose Bengal's solution to quantify; or**	Process immediately (< 6 hr) [5]
Zooplankton # (viable) (cont'd.)			**fix as above and quantify as formerly viable (Johnson and Allen 2005)**	**Process within 1 month**
Bacteria (active culturable, aerobic heterotrophic - selected taxa)	≥ 500 mL [6] [1 mL to 500 L]	sterile HDPE	Plate on appropriate media (U.S. EPA 2010) [6]	Process Immediately (< 6 hr)
Nutrients[1] -				

Table 6.4, cont'd.

Parameter	Minimum Sample Volume	Containers	Processing/Preservation Holding Time	Maximum
TN, TP total Kjeldahl N (TKN)	60 mL	varies	Varies – see standard methods (U.S. EPA 1993, 1997; APHA et al. 2008; and U.S. EPA 2010, p.39)	varies (mostly 28 days)
NO_xN, NH_xN, SRP, **SiO_2**	60 mL	varies	Varies – see standard methods as above	varies (mostly 28 days)

[1] ETV protocols that differ from those recommended above by the committee are as follows: DOC – pass sample through a GF/F filter and freeze filtrate until analysis; chlorophyll *a* and pheopigments – listed as an auxiliary parameter rather than a core parameter; protists (phytoplankton, protozoans) in the < 10 µm size class are not considered; TN, TP, total Kjeldahl N, and silica are not addressed; and dissolved inorganic phosphate is referred to here as soluble reactive phosphorus (SRP).
In situ sensors are available for measuring chlorophyll *a* as relative fluorescence units, but not as chlorophyll *a* concentrations. Chlorophyll *a* may be considered as a core parameter or as an auxiliary parameter, used as a collective indicator for algal biomass. The committee also recommends assessment of nutrients if possible, although nutrients are not considered as core parameters by the ETV.

_[2] This size category has not been considered for ballast water treatment standards by IMO (2008a,b), the ETV (U.S. EPA 2010), etc. Because many harmful organisms occur in the < 10 µm grouping, this size class should be included in assessment of BWMSs.

[3] FDA, fluorescein diacetate; CMFDA, 5-chloromethylfluorescein. Delicate protists (e.g. wall-less flagellates) mostly would not be expected to survive the process of rapid concentration of large-volume samples. As a more practical alternative than attempting to quantify viable algae and other protists from unpreserved samples, the committee recommends preserving samples immediately upon collection and then assessing intact organisms as "viable when collected," based on the fact that protists such as most algae in this general size class are known to lyse and/or decompose rapidly (minutes to several hours) after death, so that the cell contents become distorted or are lost even if the cell coverings remain (Wetzel 2001). It should be noted that vital (or mortal) stains address the question, "Is this alga alive?" in a way that is substantially different than the presence/absence of intact chloroplasts and other cell contents. Thus, the two methods sometimes do not yield the same quantitative answer and require careful calibration.

[4] The ETV recommends a sample size for the zooplankton size class of at least 1 m^3 (1,000 L), concentrated to 1 L, and analysis of 20 subsamples. However, microbead experiments conducted under "best case" conditions by the Naval Research Laboratory (Lemieux et al. 2010) indicated that the ETV protocol will not achieve acceptable precision. It should be noted that phototrophic organisms in this size class should be quantified using the protocols for phytoplankton, above.

[5] Zooplankton die-off occurs in samples held for 6 hours or more.

[6] The volumes used to quantify bacteria vary widely; as examples, the ETV recommends techniques that use as little as 1 mL, whereas MERC (2009c) uses 500 L. Since bacteria generally are abundant, the committee recommends use of 500 mL.

[7] Media suggested by the U.S. ETV (2010, p.47) for brackish/marine taxa include 2216 Marine Agar and salt-modified R2A agar; media for freshwater species may include Plate Count Agar and Nutrient broth (plus agar (15 g L^{-1}).

As a more practical alternative than attempting to quantify viable organisms from unpreserved samples, the committee recommends preserving samples immediately upon collection and then assessing intact organisms as “viable when collected.” This approach is commonly used in characterizations of microflora and microfauna assemblages in the peer-reviewed, published literature. It is based on the fact that protists and zooplankton deteriorate quickly once dead (within minutes to hours; Wetzel 2001, Johnson and Allen 2005). Effective, “fast-kill” preservatives can be used that cause death before distortion or cell lysis can occur. Standardized, accepted techniques are available for quantifying “viable when collected” protists and zooplankton from preserved material (e.g. Lund et al. 1958, Wetzel and Likens 2000, Johnson and Allen 2005; and see Section _, below). As shortcomings to this approach, dying organisms that still contain apparently intact cellular contents would be included in the “viable” estimate; and, as for counts based on unpreserved material, it is difficult to assess whether some resistant structures such as thick, opaque cysts contain organisms with intact cell contents. Because of practical and environmental health/safety constraints, neither approach avoids the problem of likely-major losses of viable organisms that occur during rapid concentration of large sample volumes.

6.2.3. **Compromises necessary because of practical constraints in sampling and available methods**

The ideal goal of standard challenge conditions that include the full (a) gradient of conditions present in the world’s ports, (b) range of organism density, (c) range of taxonomic diversity, and (d) range of organism size classes is impeded by several serious practical constraints in sampling large ballast tanks effectively, and in the methods that presently are available for quantifying viable organisms. As Lee et al. (2010, p.19) pointed out, “perfect compliance and no failure is practically, if not theoretically, impossible, particularly for microbiological organisms unless ballast water is discharged into a land-based treatment facility or ships are redesigned to eliminate the need to discharge ballast water.” This section considers how the ideal can be modified to accommodate practical considerations while accomplishing a meaningful evaluation of the efficacy of BWMSs.

A) Standardization of choices of test organisms (surrogate species)

Standard test organisms (STOs) have been defined as “organisms of known types and abundance that have been previously evaluated for their level of resistance to physical and/or chemical stressors representing ballast water technology,…added to the challenge water during testing…to determine treatment system effectiveness” (U.S. EPA 2010, p.xi). Post-treatment viability of STO taxa or life history stages is often used to evaluate the biological effectiveness of BWMSs in removing zooplankton, protists (heterotrophic and phototrophic), and bacteria.

The selection and development of STOs that are broadly resistant to treatments for use in testing BWMS performance is a fertile field of research because of the practical need (Hunt et al. 2005, Anderson et al. 2008, U.S. EPA 2010). The committee urges caution, however, since results from a very small number of taxa are broadly applied to all of the organisms in the same general grouping (e.g. protozoans in a certain size class). An assumption that first must be validated is that the selected taxa are among the most resistant to treatment, so that most organisms are eliminated when the surrogate taxa are eliminated (Ruiz et al. 2006). The fundamental challenge is to identify the best species that are "representative" of a broad range of organisms within a given size class. Good candidates are considered to be easily and economically cultured in large numbers for future full-scale testing in experimental ballast water tanks, tolerant of a wide range of environmental conditions, reliable and consistent in their response to treatment across culture batches, and resilient in withstanding ballast water tests and sampling (Ruiz et al. 2006, Anderson et al. 2008). An obvious risk is spurious results from surrogate taxa that poorly represent the larger group of organisms.

Protocols for STOs should include clear justification for use of these taxa under a defined set of conditions; careful consideration of potential confounding interactions between the STOs and natural species; and the percentage ratio of challenge organisms that are STOs versus naturally occurring taxa in the challenge water. Selection of a specific combination of STOs should be based upon extensive testing at bench and mesocosm scales, preferably by several laboratories located in different geographic regions, of a wide range of surrogate species, life histories, habitats, and source regions across environmental gradients (Ruiz et al. 2006). Consistent use of the same protocols is needed in order to minimize confounding factors and strengthen comparability. Ideally, several STOs or taxonomic subgroups, including several life stages, should be included in the tests, since confidence in interpretations can be strengthened by this redundancy. It would also be best to include multiple strains (populations) of candidate STOs if possible, to account for significant intraspecific variability in response to environmental conditions that is commonly documented, particularly among protists (Ruiz et al. 2006, Burkholder and Gilbert 2006).

B) Standardization of choices of indirect metrics (surrogate parameters)

Given the practical/logistical limitations involved in obtaining statistically meaningful estimates of specific numbers of specific organisms per unit volume, as required or proposed in rules, we recommend adding to protocols parameters that are much more rapidly and easily assessed. Examples of candidate "surrogate parameters" are shown in Table 6.5. They can be calibrated with organism numbers in laboratory tests on microcosm "ecosystems," but would be much more difficult, if not impractical, to calibrate for use with unknown types and numbers of organisms in ballast tanks. There is a critical need to carefully calibrate all potential surrogate parameters with natural populations of ballast water flora and fauna before they can be used to evaluate the performance of BWMSs – especially at the resolution of very low organism densities.

C) Increased use of tests at multiple spatial scales

Instead of relying solely on full ship-scale testing, the committee recommends for practical reasons that testing be conducted at a combination of scales as needed to address particular issues. For example, full-scale tests can pose extreme practical and logistical limitations and/or high risk in efforts to assess the effectiveness of treatment systems in removing maximal

Table 6.5. Examples of candidate "surrogate" parameters for quantifying viable organisms in ballast water, and an analysis of their utility considering methods that are presently available.*

Parameter(s)	Description	Suitability, Considering Methods Presently Available
Chlorophyll *a* (chl*a*)	"Universal" plant pigment, found in all phototrophic algae[1]; widely used as an indicator of total algal biomass[2,3]	Pros: Allows rapid processing of large numbers of samples; standardized methods widely available[2-5]. Cons: Cannot discern cell numbers per unit sample volume; not sensitive enough to detect < 10 cells ml^{-1} of small algae[6]; cellular chl*a* content highly variable (0.1-9.7% fresh weight) depending on the species[7] and the light conditions[8,9]; methods, and results depending on the method, vary widely[10-12]. Present status: Available methods do not allow reliable calibration with algal cell numbers in natural samples; improved methods are needed.
"Signature" or marker pigments	Diagnostic for cyanobacteria (zeaxanthin) and major eukaryotic algal groups (e.g. diatoms, other heterokontophytes - fucoxanthin; dinoflagellates - peridinin; chlorophytes and euglenophytes - chl *b*)[3,13]	Pros: Potentially superior to chl*a* as algal biomass indicators; more specificity to algal groups (divisions or classes); standardized methods available[13-16]. Cons: Techniques must be applied carefully to avoid artifacts and sample bias[17]; low taxonomic resolution (can sometimes be improved by screening samples using microscopy[18] to identify abundant taxa[5]). Present status: Available methods do not allow reliable calibration with algal cell numbers in natural samples; improved methods are needed
Adenylates, especially ATP (adenosine triphosphate), and Total adenylates (ATP + ADP, adenosine di-phosphate, + AMP, adenosine mono-phosphate)	Indicator of total microbial biomass in plankton, sediments[17]	Pros: ~All microbial taxa have a ~constant ratio of ATP to total cell carbon[18]; easily extracted from microbial assemblages; not associated with dead cells or detritus[19,20]. Cons: Cell ATP content varies for cells under environmental stress[21,22]; encysted cells with low metabolic activity have low ATP content (difficult to detect); total adenylates considered a better indicator of microbial biomass than ATP[17] within a given size class, but extrapolation from small sample volumes would lead to large error factors in estimating organism numbers. Present status: Available methods do not enable accurate assessment of small numbers of viable organisms per unit volume in stressed conditions within ballast tanks; improved methods are needed.

Table 6.5, continued.

Parameter(s)	Description	Suitability, Considering Methods Presently Available
INT (2-*p*-iodophenyl)-3-(*p*-nitrophenyl)-5-phenyltetrazolium chloride	Commonly used tetrazolium salt used to measure microbial activity (electron transport chain activity indicating viable organisms) in surface waters, biofilms, and sediments (freshwater to marine)[23-25]	Pros: INT accepts electrons from dehydrogenase enzymes and is reduced to a reddish colored formazan (INTF) - can be quantified by simple colorimetric analysis after a very short incubation time[26]; total cell numbers are quantified under epifluorescence microscopy using a counter-stain (e.g. acridine orange[27]) - proportion of population that is metabolically active is then estimated; very sensitive method even at low microbial biomass and low temperatures[27], with resolution at the level of individual cells[28]. Cons: Can miss cells with very low respiration (e.g. cysts), or cells that do not use INT as an electron acceptor[28]; still requires microscopy (tedious, time-consuming). Present status: Shows promise for use with various size classes of microorganisms in ballast water.
RNA, DNA	Quantitative PCR and related techniques; molecular and genomic probes[29-31]	Pros: Reliable quantification of targeted taxa from environmental water samples if PCR inhibitors can be removed and molecular material can be efficiently recovered[29,30]. Cons: More research is needed to test the degree to which these can reliably discern between viable and non-viable cells, or infective and non-infective cells, or toxic and nontoxic cells, unless supplemented by other techniques[31-34]. Present Status: Available methods do not allow reliable calibration with living algal cell numbers in natural samples; quantitative methods are emerging[35,36].

* References used: [1] Graham et al. (2009); [2,3,4,5] Wetzel (2001), Jeffrey et al. (1997), US EPA (1997), Sarmento and Descy (2008); [6] MERC (2009c); [7] Boyer et al. (2009); [8,9] U.S. EPA (2003), Buchanan et al. (2005); [10-12] Bowles et al. (1985), Hendrey et al. (1987), Porra (1991); [13] Schlüter et al. (2006); [14,15,16] Mackey et al. (1996), Jeffrey and Vest (1997), Schmid et al. (1998), Schlüter et al. (2006); [17] Sandrin et al. (2009); [18] Karl (1980); [19,20] Holm-Hansen (1973), Takano (1983); [21,22] Inubushi et al. (1989), Rosaker and Kleft (1990); [23-25] Songster-Alpin and Klotz (1995), Posch et al. (1997), Blenkinsopp and Lock (1998); [26] Mosher et al. (2003); [27] Sandrin et al. (2009); [28] Posch et al. (1997); [29]Caron et al. (2004); [30]Kudela et al. (2010); [31]Karlson et al. (2010); [32]Guy et al. (2003), [33]Audemard et al. (2005), [34]Burkholder et al. (2005), [35]Jones et al (2008), [36]Bott et al. (2010).

densities of harmful organisms, or mixes of representative organisms within certain density ranges. These risks support the use of sized-down mesocosm treatments (hundreds to thousands of liters; Ruiz et al. 2006, MERC 2009a-c) that are larger and therefore more realistic than bench-scale microcosms, but more manageable in volume than ballast tanks (Figure 6.1). Sized-down treatments help to reduce risks to human health safety and receiving aquatic ecosystems for testing treatment system effectiveness at removing toxic substances and residues that are part of the treatment process. As Ruiz et al. (2006, p.10) stated, "Economy of small scale and ease of manipulating environmental variables and community assemblage at the laboratory and intermediate scales make it possible and practical to estimate if a ballast water treatment process and system is likely to be effective over the full range of physical [, chemical,] and biological conditions expected in the field;…the same regime on a ship would prove logistically and financially very unwieldy. Thus, smaller scale tests demonstrate the treatment's performance and capacity across a wide range of relevant state variables…." This approach also allows more precise, controlled sampling during test trials (MERC 2009d). At larger scales, practical limitations restrict the number of conditions that can reasonably be tested, and testing is directed more toward ensuring functionality of the engineered system rather than understanding the treatment process under various conditions.

Small-scale (benchtop or laboratory) experiments minimize logistics and expense, and they can provide proof of concept in assessing whether a given treatment meets expectations (Ruiz et al. 2006). For example, if a BWMS is planned for use across the salinity gradient, then its efficacy should be tested across all three salinity ranges (Table 3). Logistically, however, it may be feasible to test two salinity ranges at full scale, but not the third. In such cases, small-scale and intermediate-scale (see below) tests could be completed using the third salinity range. Likewise, the committee recommends that bench-top and mesocosm experiments complement full-scale testing

6.2.4. *Testing shipboard treatment systems: Inherent mismatch between viability standard and practical protocols*

In the previous section, we reviewed features of current procedures for testing BWMSs that could be improved with existing knowledge and technology. In this section, we review additional aspects of current procedures that may not really accomplish the stated goals because of inherent limitations in current knowledge and technology. All of the six issues we consider below stem from the difficult – perhaps the impossibility, given current technology – of accurately enumerating only those organisms that are viable (alive). Current practices result from trying to directly assess the legal standards (which focus on viable organisms). This section is aimed especially at organisms <50um, because the challenge of determining viability of larger organisms may be secondary to the problem of sampling an adequate volume to assess the concentration aspect of the legal standard (see earlier section of this report on statistics). The committee recommends that new approaches be developed, including procedures that address the standards indirectly, but have the benefit of practicality. In general, the committee recommends that the limitations of testing protocols for determining "viability" and/or "living" must be assessed and overcome with new standardized protocols, including indirect metrics that can be reliably correlated with the concentration of viable organisms (as we began to address in Table 6.5 above).

As Lee et al. (2010, p. 72) aptly state, "A discharge standard of 'zero detectable organisms' may appear [emphasis added] very protective; however, the true degree of protection depends on the sampling protocol." Here, a viable or living organism is defined as in U.S. EPA (1999), namely, as an organism that has the ability to pass genetic material on to the next generation. The percentage of non-viable cells can vary markedly, for example, from 5-60% among phytoplankton taxa, and in general, non-viable organisms are believed to represent a substantial component of the total plankton (Agusti and Sánchez 2002). There are several fundamental problems confronted in present attempts to quantify viable organisms to evaluate ballast water treatment efficiency, outlined as follows.

A) Death of organisms by rapid concentration from large volumes

A major issue confounding the realistic representation of viable organism concentrations is that the rapid concentration of organisms from large volumes into small volumes (which is a necessary prerequisite of enumeration) causes the death of many organisms across size classes. This concentration step must be accomplished quickly before organisms die – for example, within 6 hours for zooplankton. There is a fundamental disconnect in these requirements: It is difficult if not impossible to rapidly concentrate microflora and microfauna from very large volumes (hundreds of liters) by available filtration or centrifugation techniques without killing many of the organisms (e.g. Turner 1978, Cangelosi et al. 2007). Such rapid concentration techniques can cause the loss of a major fraction of the viable organisms, even when dealing with small sample volumes such as 1 liter (Darzynkiewicz et al. 1994). This problem affects zooplankton and protist size classes, especially delicate species such as wall-less algal flagellates. Thus, even if viable organisms can be distinguished from dead organisms when counted, what cannot be known is the proportion of the dead organisms that were actually alive at the time of sampling. It should be noted that concentration-related losses do not affect the smallest size classes, bacteria and viruses, because they are so abundant in most fresh, estuarine, and marine waters that it usually is not necessary to concentrate them from whole water samples prior to analysis by standard microbial techniques (U.S. EPA 2010; see below).

B) Organism viability is difficult to determine

Organism viability is not easily detected by a single morphological, physiological, or genetic parameter, making it advantageous to use more than one approach (Brussaard et al. 2001). However, the procedures used are specific to some taxonomic groups (e.g., vital stains), have varying degrees of uncertainty in categorizing live versus dead, and even the recommended procedures have practical limitations because of time constraints. For example, the ETV (U.S. EPA 2010) defines dead zooplankton operationally as individuals that do not visibly move during an observation time of at least ten seconds. Since live zooplankton may not move over that short period, death is verified by gently touching the organism with the point of a fine dissecting needle to elicit movement. However, the ETV acknowledges that if every apparently dead zooplankter in a concentrated subsample was probed and monitored for at least 10 seconds, analysis of the sample could be extended enough to increase the potential for sample bias due to death of some proportion of individuals that had survived the sampling and concentration procedures. In other words, the currently applied methods cannot really be followed. The results are therefore most appropriately viewed as an index of the number of viable organisms, and we recommend consideration of a wider variety of indices that have the potential to be quicker at least, if not more accurate. These include parameters that may be correlated to the abundance of viable organisms, as discussed in the previous section (Table 6.5), and techniques to distinguish living from dead individuals prior to enumeration by other methods (e.g., microscopy). We elaborate on the latter here.

Fluorescent stains have shown promise in detecting some live organisms or groups. For example, the fluorogenic substrate Calcein-AM (Molecular Probes Inc.) is used to stain live cells that have metabolic esterase activity (Kaneshiro et al. 1993, Porter et al. 1995). Once the colorless, nonfluorescent substrate is inside the living cell, its lipophilic blocking groups are cleaved by nonspecific esterases to a charged green fluorescen product that cannot pass across the plasma membrane. Dead cells cannot hydrolyze the Calcein-AM or retain the fluorescent product. Use of FDA, sometimes in combination with CMFDA (Table 6.4), is based on measuring intracellular esterases in live cells (Laabir and Gentien 1999, Hampel et al. 2001). FDA was described as a reliable, efficient method to quantify concentrated viable freshwater organisms in the 10- to < 50 µm size class from ballast discharge (Reavie et al. 2010). However, various algal species differ in their uptake of FDA and CMFDA, and other particles in a given sample can also fluoresce (Garvey et al. 2007, MERC 2009c). The vital stain propidium iodide (PI), in combination with molecular probes, has been used to discern live from dead bacteria (Williams et al. 1998), but the number of false positives can vary widely (Steinberg et al. 2010), and this stain cannot be used to assess algal viability because its emission spectrum overlaps that of chlorophyll (Veldhuis et al. 2001). The committee recommends completion of on-site validation before selecting a viability method, including evaluation of false positives and false negatives.

As mentioned above, detection of infective viruses has received relatively little attention in ballast water treatment. Waterborne illnesses can involve a wide array of viruses; for example, enteric viruses that can be transmitted by water include poliovirus, coxsackievirus, echovirus, human caliciviruses such as noroviruses and sapoviruses, rotaviruses, hepatitis A virus, and adenoviruses (Howard et al. 2006). Considering pathogens of aquatic organisms, aquatic ecosystems are poorly understood with respect to the diversity of viral pathogens of beneficial aquatic life (Suttle et al. 1991, Griffin et al. 2003, Mann et al. 2006, Suttle 2007). Viruses also cross size classes; in environmental samples, many are in range of nanometers, but some can be nearly 3 µm in maximum dimension (Bratbak et al. 1992), and their strong tendency to adsorb onto sediment particles (> 6 µm) can effectively "boost" them into a much larger size range as well (Bosch et al. 2005).

The U.S. EPA (2001) requires a 99.9% reduction in the total number of human enteric viruses in water for human consumption. In practice, this requirement is met based on treatment alone, although the U.S. EPA acknowledges that removal actually can only be accurately assessed by monitoring finished waters over time. Ultra-filtration protocols have been developed for concentrating and enumerating human enteric viruses (Fout et al. 1996, U.S. EPA 2001), but these techniques do not discern potentially infectious from non-infectious viruses. Environmental water samples have also been evaluated for human viral pathogens using standard techniques for in vitro cultivation, an approach that is affected by the same problems confronted for detection of viable bacteria – the techniques are expensive, time-consuming, labor-intensive, and can easily miss various groups of infectious viruses (Fout et al. 1996). Rapid, sensitive molecular methods for viral nucleic acid detection have been recently developed but, again, most cannot discern potential infectivity. The intercalating dye propidium monoazide (PMA) has shown promise in detecting potentially infective coxsackievirus, poliovirus, echovirus, and Norwalk virus (Parshionikar et al. 2010). In other promising research, Cromeans et al. (2005) included additional processing steps such as specific capture by cell receptors for Coxsackie B viruses in vitro, followed by molecular detection of viral nucleic acids in the captured viruses; or selection/detection of specific RNA present in host cells only during virus replication. Real-time assays (30-90 minutes) were also developed for enterovirus, hepatitis A virus, Adenovirus, and Norovirus detection. There remains a pressing need for new, commercially available technology that can discern infectious from non-infectious viruses (Cromeans et al. 2005, Parshionikar et al. 2010).

C) Special challenges of resistant or nonculturable stages in attempts to assess viability

Resting stages (e.g., cysts) of some bacteria, phytoplankton, protists, zooplankton and metazoans are particularly resistant to motility, staining, and any other tests. For example, the protist size class (10 to < 50 µm) includes many species (microalgae, heterotrophic protists, metazoans) that form dormant cells or resting stages, or cysts (Matsuoka and Fukuyo 2000, Marrett and Zonneveld 2003). Cysts from potentially toxic dinoflagellates are commonly found in ballast waters and sediments (Hallegraeff and Bolch 1992, Dobbs and Rogerson 2005, Doblin and Dobbs 2006). These cysts have been used as model indicator organisms to assess ballast water treatment efficiency (Anderson et al. 2004, Stevens et al. 2004), based on the premise that treatments which can eliminate the cysts likely also eliminate other, less resistant organisms (Bolch and Hallegraeff 1993, Hallegraeff et al. 1997).

Because resistant cells often have a low metabolic state and thick, multi-layered walls that are impermeable to many stains (Romano et al. 1996, Kokinos et al. 1998, Connelly et al. 2007), their viability can be difficult to assess without culture analyses that may require weeks to months (Montresor et al. 2003, U.S. EPA 2010). Improved methods have been developed for some algal groups (Binet and Stauber 2006, Gregg and Hallegraeff 2007) but, overall, as the ETV (U.S. EPA 2010, pp.46-47) states, “At present, no rapid, reliable method to determine cysts’ viability is in widespread use, and the FDA-CMFDA method has yielded variable results with dinoflagellates and cyst-like objects.” The ETV recommends use of this method as a “place holder” until more effective methods become available.

The effectiveness of ballast water treatment in removing viable bacteria is commonly evaluated by using multiple bacterial media in combination with taxon-specific molecular techniques (MERC 2009c, U.S. EPA 2010 and references therein). Colonies are monitored and quantified after ~1 to 5 days, depending upon the organism and its growth. These methods enable detection and quantification of viable, culturable cells. However, it has been repeatedly demonstrated that bacterial consortia across aquatic ecosystems commonly have a substantial proportion of cells which are active (viable) but nonculturable (Oliver 1993, Barcina et al. 1997 and references therein). These cells obviously would be overlooked in culturing techniques, a problem that would result in failure to detect viable cells of bacterial pathogens in treated ballast water. Under some conditions, the nonculturable organisms can regain activity and virulence (Barcina et al. 1997 and references therein).

D) Biased counts due to live, motile species changing their location in counting chambers

At the other extreme from resting stages are living organisms that are difficult to enumerate because they are highly mobile. Organisms are typically enumerated in counting chambers, based upon an underlying premise that the cells do not change their location in the chamber. However, many protists move rapidly by means of flagella or other structures. Because they do not maintain their position in a counting chamber, as live cells they could be counted multiple times. Moreover, their sudden movement can disrupt the locations of other cells in the chamber, mixing cells that may have been counted with others that have not yet been counted. For these reasons, reliance on live counts can easily yield unreliable data.
E) Summary: indirect metrics for enumeration of viable cells should be added to standard protocols

Consideration of the above points – death during concentration of organisms, lack of reliable procedures to assess viability (especially for resting stages of many taxa), movement of live organisms in counting chambers that can result in serious quantification errors – leads the committee to recommend that alternative approaches, including enumeration of preserved organisms and indirect metrics of the concentration of viable organisms, be tested and added to standard protocols. These more inherent limitations add weight to the more practical considerations in section II above: the practical and inherent limitations converge as an argument for the greater development, testing, and implementation of indirect metrics of the concentration of viable organisms, including both STOs and surrogate parameters. Adding parallel testing of indirect metrics to tests currently underway in testing facilities from different geographic regions could rapidly yield comparisons on which decisions for future testing could be made. Very likely, a combination of approaches will prove to be the most advantageous in estimating the concentration of viable organisms of different taxonomic groups

6.3. Approaches to compliance/enforcement of ballast water regulations and potential application to technology testing

The US EPA has extensive experience in effective compliance and enforcement of discharge regulations. However, given the nature of ship ballast water discharge, new approaches will likely be needed. Both initial testing of treatment systems (6.2.2 – 6.2.4) and methods currently available for potential compliance and enforcement monitoring are complex, slow and expensive. Statistical (see Section 3, this report) and logistical limitations related to collection of appropriate sample volumes and detection/quantification of live organisms in practice, mean that it may often be impossible to directly assess whether a vessel can meet all the numerical standards for viable organisms (King and Tamburri, 2010). No information was provided to the committee on whether protocols and systems for compliance monitoring (whether voluntary by ship operator or legally required) and enforcement were being considered alongside the development and testing of treatment systems. The committee feels that it is essential that these be developed in concert with treatment testing to avoid a situation where the creation of enforceable policy or rules is difficult or impossible.

The practical and inherent limitations suffered by the full protocols for certification testing of BWMSs (6.2.2 – 6.2.4) have even greater force in the context of routine inspections (either self-inspections or regulatory inspections) (King and Tamburri 2010). They are simply not possible to use in the compliance and enforcement context. If alternative protocols that are practical for inspections are not developed, then neither self-compliance efforts nor regulatory enforcement will be possible once a system is installed on a ship.

For example, treatment system malfunctions are inevitable. If some types of mechanical failure are not obvious to the operator or inspector, release of organisms may reach and maintain non-compliant levels for long periods of time with no detection of the malfunction, no penalty, and therefore no incentive to detect and fix the system. Unenforceable rules are bound to fail to meet the goal of reducing invasions. Therefore, the committee recommends that EPA develop a phased approach for BWMSs that includes metrics appropriate for compliance monitoring and enforcement.

A potential solution is the use of a phased compliance reporting, inspections, and monitoring approach, described below, which involves a series of steps that increase the likelihood of detecting non-compliance but also increase in cost and logistic challenges (King and Tamburri 2010).

- Reporting – Vessel owner or ship master submits reports on the type of certified treatment system onboard and documentation demonstrating appropriate use and maintenance.
- Inspections – Enforcement official boards vessel and inspects the certified treatment systems to verify use and appropriate operations and maintenance.
- Measures of system performance – Indirect or indicative water quality measures are collected autonomously (using commercially available instruments), or by inspectors, that demonstrate appropriate treatment conditions have been.
- Indirect measures of non-compliance – Indirect metrics (Table 6.5) of abundances of live organisms are collected autonomously, or by inspectors, for indications of clear non-compliance.
- Measures of discharge standard – Direct measures of concentration of live organisms in the various regulated categories are made by specially trained technicians, with statistically appropriate sampling, and validated analyses and methodologies.

Protocols assessing indirect surrogate measures to quantify viable organisms should be further developed for quick, easy, and defensible shipboard compliance monitoring (see 6.2.2 - 6.2.4).

6.4. Reception facilities as an alternative to shipboard treatment

International, existing federal, and proposed federal regulations allow for the transfer of marine vessel ballast water and sediment to reception facilities (Facilities). In such cases, it is the Facility, rather than equipment on board the marine vessel, that serves to inactivate or kill the organisms in ballast. Various studies have envisioned Facilities as either built on land or installed as port-based marine vessel platforms.

The ballast water would be pumped off the marine vessel to the Facility through main deck fittings. High transfer rates and volumes might be similar to a tank ship discharging liquid petroleum products to a refinery through articulated "Chiksan" piping. Low transfer rates and volumes might be similar to a ship receiving fuel oil through hoses from a bunkering barge. The Facility would then employ a system of procedures and equipment to treat the ballast water before it is released into local waters.

Charge question 3B asks: "What are the principal technological constraints or other impediments to the development of ballast water treatment technologies for use onboard vessels to reliably meet any or all of the discharge standards?" A key finding for that charge question is that the architecture and operation of the marine vessels themselves are limiting factors. Marine vessels are subject to many factors that are challenging to water treatment procedures including: corrosion and vibration, small and busy crews, limited space and weight allowances. Facilities, relieved of many or all of those constraints, show promise to achieve more stringent ballast water treatment standards at lower cost than BWMS located on board marine vessels.

Section 6.4.1 provides background on Facilities. Section 6.4.2 presents a literature review and a screening-level economic analysis that compares Facilities to BWMS. Section 6.4.3 discusses implementation challenges and identifies additional information needs. Section 6.4.4 summarizes comparative features of shipboard BWMSs and shore-based Facilities. Section 6.4.5 provides a recommended path forward.&&&&.

6.4.1. ***Background on Facilities***

A) Regulatory framework

The employment of Facilities to handle ballast water and sediment is currently part of the international and federal regulatory framework. The International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004 (Convention) identifies handling of marine vessel sediment in Article 5 – Sediment Reception Facilities. Regulation B-3.6 of the Convention applies Facilities to ballast water more broadly: "The requirements of this regulation do not apply to ships that discharge Ballast Water to a reception facility designed taking into account the Guidelines developed by the Organization for such facilities." The Guidelines for Ballast Water Reception Facilities (G5) apply more broadly to ballast water: "The purpose of these guidelines is to provide guidance for the provision of facilities for the reception of ballast water as referred to in Regulation B-3.6 of the Convention. These guidelines are not intended to require that a Party shall provide such facilities. The guidance is also intended to encourage a worldwide uniform interface between such facilities and the ships without prescribing dedicated shoreside reception plants." Similar language is in the current and proposed U.S. federal rules.

B) Transfer and Reception

Use of Facilities requires that the ballast water and sediment are transferred from the marine vessel, and received by the Facility. Similar transfers occur routinely in marine vessel operations for the transfer of liquid petroleum either as fuel oil bunkers or bulk cargo (Figure 6.2).

Figure 6.2. The left photo shows a bunker barge on the left transferring fuel oil to tank ship (Wendell Koi, Foss Maritime). The hose is 200 mm and the transfer rate is approximately 800 metric tons per hour. The right photo shows a Chiksan® style marine loading arm connecting a tank ship to a shore-based facility (www.fmctechnologies.com). These loading arms are commonly 500 mm nominal diameter and are capable of high volume flow rates**.**

Adapting these transfer methods to ballast water presents different challenges for different marine vessel types. For example, little retrofit might be necessary for a crude oil carrier. These ships routinely transfer oily ballast water, known as non-segregated ballast water. A carrier preparing to load crude oil will transfer the oily ballast water to a reception facility that removes the oil before it is pumped into the harbor. Similarly, some containerships and car carriers cross-connect their ballast water mains with their fire mains that already have deck connections. In contrast, a Great Lakes bulk carrier would require a significant refit of piping, pumping, and power generation refit to transfer ballast water to a deck fitting

6.4.2. ***Promise of Facilities to cost effectively meet higher standards***

Many laws, regulations, guidelines and treaty conventions, including IMO G-1 and G-5, recognize the potential of reception facilities to treat ballast discharges. Nevertheless, reports on ballast water treatment by the U.S. EPA and U.S. Coast Guard have not addressed Facilities (EPA 2001; Albert et al. 2010; US Coast Guard 2008). For published studies that do address Facilities, analyses and opinions on the desirability and feasibility of Facilities are mixed and some sources contradict others. Some studies, for example, concluded that Facilities are a technically feasible option either for the industry as a whole or for some part of the industry

(Pollutech 1992; NRC 1996; Oemke 1999; CAPA 2000; California SWRCB 2002; Brown and Caldwell 2007, 2008). A few concluded that cost or other factors could limit their use to part of the industry (Victoria ENRC 1997; Dames & Moore 1998, 1999; Rigby & Taylor 2001a,b; California SLC 2009, 2010). Here we use the published literature to identify the major potential advantages of on-shore facilities, including concomitant disadvantages where they occur. In the subsequent section, we focus on the major potential disadvantages of on-shore facilities. For both sections, we also identify significant gaps in information. Appendix 1 provides more details on many of these analyses.

Specifically in this section, we identify the potential of Facilities to achieve more stringent ballast water standards at less overall cost compared to BWMS. The discussion considers that fewer Facilities may be advantageous relative to more vessel-based systems; and that Facilities with fewer physical restrictions can use more effective technology and processes. A shift from vessel-based BWMS to a Facility approach is analogous to a shift from household septic tanks to centralized waste treatment plants. The purpose of this section is to identify Facilities as a technically feasible, and possibly cost effective, solution to providing a higher level of environmental protection. To simplify the discussion, only the "on-shore" variation of Facilities is reviewed. Facilities located on board port-based vessels are not addressed in this discussion.

Comparison of onshore Facilities to vessel-based BWMS

1) Number of treatment plants and total treatment capacity

In shipboard treatment, plants are installed on each ship, which in nearly all cases treat ballast water during uptake, discharge, or both. These plants must be large enough to treat the ship's maximum ballast uptake or discharge rate (ABS 2010). In contrast, onshore facilities serve a number of ships, and since all ships do not arrive and discharge ballast water simultaneously, the treatment capacity needed is less. Also, substantial ballast water storage capacity could be included in an onshore plant, which could reduce the needed treatment capacity to the average ballast water discharge rate (AQIS 1993a; Ogilvie 1995; CAPA 2000; Brown and Caldwell 2007, 2008). The number of plants needed for shipboard treatment exceeds the number needed for onshore treatment by a factor of at least 20 (and possibly much higher), and the volumetric capacity needed for shipboard treatment also greatly exceeds that needed for onshore treatment (Appendix 1). More detailed analyses are required to decrease uncertainty in these assessments.

2) Constraints on treatment

Constraints on shipboard treatment include limited space, limited power availability, limited treatment time and ship stability challenges (Pollutech 1992; AQIS 1993a; Aquatic Sciences 1996; NRC 1996; Cohen 1998; Oemke 1999; Reeves 1999; California SLC 2010; Albert & Everett 2010, Section XX). These constraints are largely absent in onshore systems.

3) Treatment methods available

Any treatment used on ships can be used onshore; however, there are methods available for onshore use that cannot be used on ships because of the constraints listed above. Technologies with potential for use onshore but not on shipboard include common water or wastewater treatment processes such as settling tanks, flotation and granular filtration, and the use of chlorine gas for disinfection (Cohen & Foster 2000); and less common processes including microfiltration, ultrafiltration and reverse osmosis (AQIS 1993a; California SLC 2010). Efficacy of these processes is discussed in Appendix 1.

4) Plant operation by trained water/wastewater treatment personnel

Shipboard treatment plants will likely be operated and maintained by ships' regular crew members as added duties (NRC 1996; California SLC 2010). Studies have noted that many ship's crews are already overburdened and may struggle to adequately operate and maintain the treatment plant (Pollutech 1992; AQIS 1993a; Aquatic Sciences 1996; Reeves 1998). Operation by trained, dedicated personnel in onshore plants should often result in more reliable performance (Cohen 1998; California SWRCB 2002; Brown & Caldwell 2007; California SLC 2010). Maintenance and repair work are more likely to be done reliably, and replacement parts obtained more quickly, in onshore plants (AQIS 1993a; Aquatic Sciences 1996; Cohen 1998; Cohen & Foster 2000).

5) Safety

Restricted working spaces and difficult or hazardous working conditions at sea (AQIS 1993a; Cohen 1998; Cohen & Foster 2000) increase the risk of accidents with shipboard treatment. The storage and use of biocides or other hazardous chemicals pose greater risks to personnel in shipboard than in onshore applications (AQIS 1993a; Carlton et al. 1995; Reeves 1998; Cohen 1998; Cohen & Foster 2000) and greater risk of accidental discharge to the environment (Pollutech 1992; AQIS 1993a; Carlton et al. 1995). Because many treatment processes cannot be used onboard (as discussed above), shipboard systems might rely on biocides more than onshore systems do.

On the other hand, increased safety risk may accompany transfers of ballast water to on-shore facilities. Handling of ballast water transfer connections, including the attachment of large hoses or articulated piping manifolds to off-load ballast water, is recognized as an increased risk to the safety of the ship's crew. Although this is common practice for large tank ships, many ships do not have crews experienced in these operations and safety programs for this new activity would need to be implemented.

6) Reliability

Operation and maintenance by dedicated wastewater treatment staff, should increase the reliability of the treatment system. Extensive experience with water and wastewater treatment plants provides a basis for estimating the expected long-term performance of onshore ballast water treatment that use the same treatment processes. In addition, onshore plants should generally have more flexibility to build redundancy into the system design.

7) Adaptability

Because of space restrictions on ships and structural cost factors that make treatment components a smaller part of the total cost of onshore systems, it is both physically and financially easier to retrofit, replace, or upgrade onshore than shipboard systems. Brown and Caldwell (2008) note that onshore systems would "provide treatment flexibility, allowing additional treatment processes to be added or modified as regulations and treatment targets change."

8) Compliance monitoring and regulation

The effort and cost of regulatory monitoring and enforcement needed to achieve a given level of compliance would be much less for a small number of onshore treatment plants compared to a much larger number of mobile, transient, shipboard treatment plants, most of which are foreign-owned or foreign-flagged, which are accessible only when in U.S. ports, usually for brief periods (AQIS 1993a; Ogilvie 1995; Aquatic Sciences 1996; Cohen 1998; Dames & Moore 1999; Oemke 1999; Cohen & Foster 2000; California SWRCB 2002; Brown and Caldwell 2007; California SLC 2010). Some studies noted that only onshore treatment puts the responsibility for monitoring, control and effectiveness entirely in the hands of the authorities responsible for protecting the receiving waters, without reliance on ships' logs or on authorities in originating ports (AQIS 1993b; Dames & Moore 1999; California SWRCB 2002).

9) Overall effectiveness

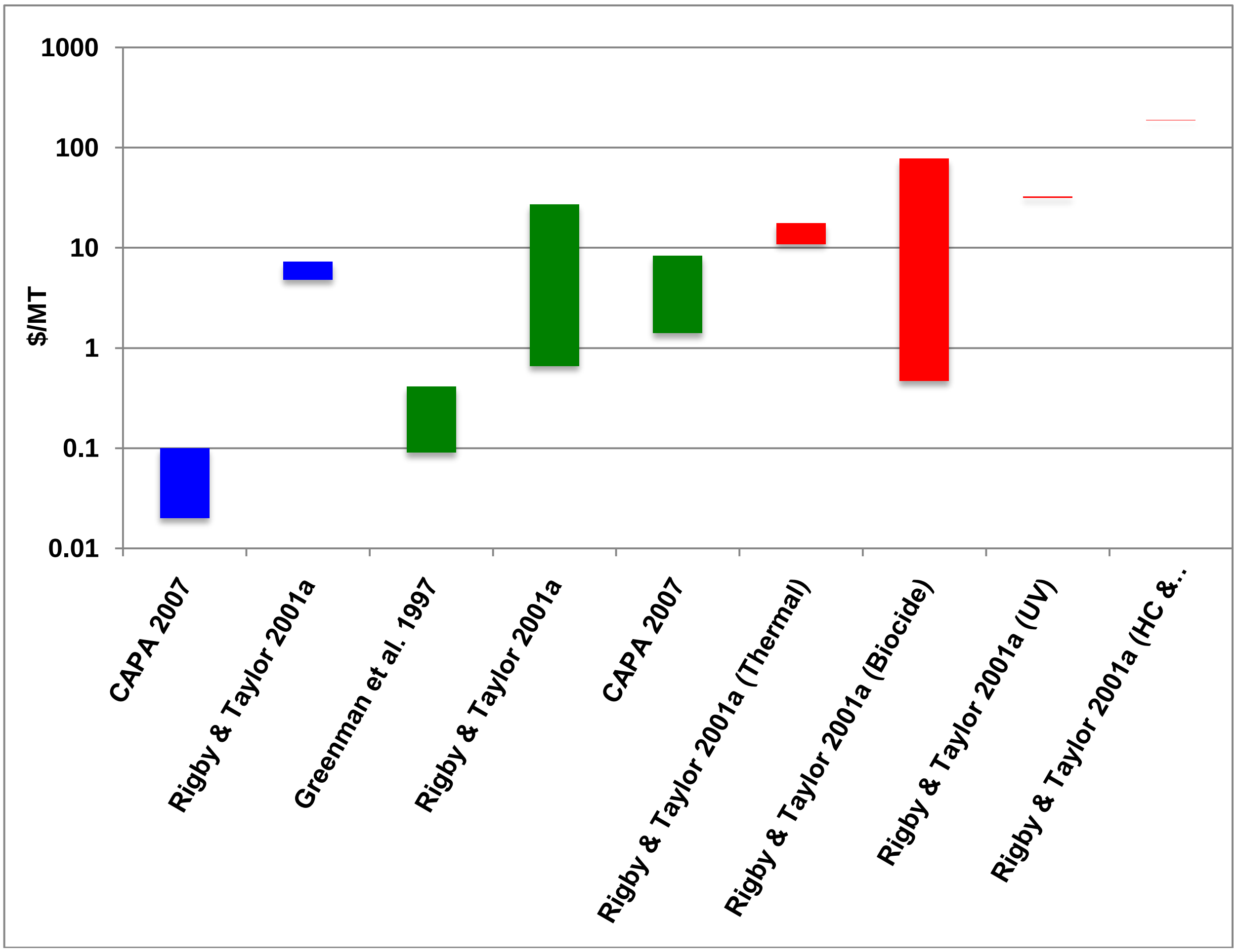
The absence of comparable space, time or power constraints, the use of common and effective water and wastewater treatment processes, operation and maintenance by trained personnel, and the ability to install extra capacity and redundancy would make onshore treatment more consistently effective than shipboard treatment at removing or killing organisms in ballast water. Cost factors that make it possible to concatenate a larger and more effective set of treatment processes and that make it easier to retrofit, replace, or upgrade equipment also increase the effectiveness of onshore relative to shipboard treatment.

10) Comparison of cost of on-shore facilities to shipboard BWMS

A comprehensive comparison of the likely cost of onshore facilities to that of shipboard BWMS is not available but is needed. The U.S. Coast Guard compiled a table of cost estimates from different studies (U.S. Coast Guard 2002). Figure 6.3 shows all the estimates that were expressed as costs per metric ton or cubic meter of ballast water, and thus in a form that can be compared. In these estimates, onshore treatment is generally more expensive than ballast water exchange and less expensive than shipboard treatment, although there is considerable overlap.

One screening-level analysis (Appendix 1), suggests that costs for onshore treatment may be less than for shipboard BWMS. This analysis is, however, incomplete from a global perspective. For example, unless Facilities are available in most, if not all, global ports, then ships transiting internationally may also need a shipboard system. In addition, a comprehensive assessment will need to identify vessel fleets that might practically employ a network of Facilities that cover all of their ports-of-call. Based on that assessment, site-specific estimates for Facilities could be developed that account for local land use issues as well as the particulars of the ballast water management needs of the serviced vessel fleet.

Figure 6.3. Cost estimates listed in U.S. Coast Guard (2002). The Coast Guard converted Australian estimates to U.S. dollars at the Oct. 16, 2001 exchange rate, but did not adjust estimates for inflation. Cost estimates for ballast water exchange are in blue, for onshore treatment in green, and for shipboard treatment in red.



6.4.3. *Challenges to widespread adoption of Facilities*

Despite regulatory acceptance and identified advantages, there are no current Facilities available to handle ballast water. At the same time, there are ten internationally Type Approved shipboard BWMS of which hundreds have been sold for installation on board marine vessels. This appears to be a result of the framework of the 2004 Convention that phases in standards by marine vessel ballast water capacity, rather than on a port-by-port basis. To avoid the risk of arriving in a port without an operational Facility, operators are opting to install equipment on board each marine vessel. This section elaborates on this trajectory of implementation of shipboard BWMS, and identifies other challenges facing implementation of Facilities including those with the regulatory framework, potential impact on ship revenues, equipment and operations, logistics, and implementation schedules.

A) Challenges with regulatory framework

The current regulatory framework phases in ballast water management standards based on ballast water capacity and construction date of marine vessels. For example, the U.S. proposed phase 1 timetable would require all new vessels constructed starting in 2012 to meet discharge standards on delivery (Table 6.6). To be in compliance while employing the Facility approach to ballast water management, the marine vessel operator must be assured that there will be an operational Facility at all anticipated ports-of-call where ballast water discharge might be expected.

Table 6.6. U.S. Proposed Phase 1 Timetable

Vessel's ballast water capacity (cubic meters, m³)	Vessel's construction date	Vessel's compliance date
New vessels: All	On or after January 1, 2012	On Delivery.
Existing vessels:		
Less than 1500	Before January 1, 2012	First drydocking after January 1, 2016.
1500–5000	Before January 1, 2012	First drydocking after January 1, 2014.
Greater than 5000	Before January 1, 2012	First drydocking after January 1, 2016.

An ideal candidate for the Facility approach might be U.S. West Coast vessels loading crude oil in Valdez, Alaska as part of the Trans Alaska Pipeline System. Alaskan Tanker Company operates four of these carriers, transferring crude oil from Valdez to refineries in Puget Sound, San Francisco Bay, Long Beach, and Barber's Point. In theory, these vessels would only discharge ballast water in Valdez and could therefore be serviced by a single Facility. However, a query of the National Ballast Information Clearinghouse indicates that although the vast majority of ballast discharges were in Valdez, this four vessel fleet would have also required service from Facilities in six additional locations (National Ballast Information Clearinghouse 2008. NBIC Online Database. Electronic publication, Smithsonian Environmental Research Center & United States Coast Guard. Available from http://invasions.si.edu/nbic/search.html; searched 12 February 2011).

Crude oil trade examples are similar to container and other ships operating on dedicated routes with a similar number of ports-of-call. For example, many vessels call on many ports within a given year either by schedule or because they operate on the spot market where their next port of call is not known until a contract is fixed. The Höegh Trooper is a roll-on/roll-off ship that has been used as a test platform for a multistage ballast treatment system; this vessel called on over 40 different ports in 2009 (www.hoegh.com).

The barrier to reliance on Facilities is established by the regulatory framework, namely the uncertainty of widespread adoption of a Facility approach. This uncertainty creates a positive feedback calculation of benefits and risks that makes Facilities unattractive to vessel owners. To incentivize the construction of a network of Facilities, adequate revenue from ships must be likely. For the vessel, Facilities must be available in all anticipated ports-of-call. However, if some ports will not have Facilities, then marine vessels that may call there will need to have a shipboard system. If many marine vessels therefore are compelled to install shipboard systems, the potential market for Facilities has shrunk correspondingly, reducing the incentive for those who might invest in Facilities.

B) Potential impacts on vessel revenue

Marine vessels are designed to perform tasks such as movement of people and goods. The revenue of these vessels is typically quantified in terms of daily rates. The table below gives two vessel examples, two periods to reflect the recent rate fluctuations, and provides hourly, daily, and weekly rates.

Table 6.7. Marine Vessel Example Rates (Review of Maritime Transport, 2009 and 2010)

	Vessel Rate in U.S. Dollars		
Vessel Example	One Hour	One Day	One Week
Tanker (VLCC) May 2008	6,700	160,800	1,125,600
Tanker (VLCC) Avg. 2009	1,600	38,500	269,500
Bulker (Cape) June 2008	7,300	176,200	1,233,400
Bulker (Cape) Avg. 2009	1,500	35,300	247,100

A review of potential impacts from delays in managing ballast water is provided below. For the purposes of the following theoretical examples the following is assumed: daily rate of $60,000; onboard BWMS cost of $2 million; a voyage duration of seven days; forty voyages per year; and an operating life of ten years.

A marine vessel that is not able to comply with ballast water management requirements may not be allowed to discharge ballast water, and therefore be unable to conduct cargo operations, take on fuel oil, or perform other mission critical tasks. In any of these cases, the vessel would sit idle until a solution was developed. The cause of this could be a non-compliant or non-functioning BWMS, or the lack of an available Facility. In this case, because the vessel would not be able to take cargo, it would lose its voyage. The loss would be $420,000 (one week at daily rate) plus penalties and lost fuel.

Facilities operations could delay the mission of the marine vessel. A few examples include:

- The Facility is barge mounted, and it takes time to secure the barge alongside the ship and make fast the ballast connection and subsequently let it go. It would also take time to make fast and subsequently let go the ballast connection to a shore-based facility.
- A barge-mounted Facility might not be available. Either the barge or the assisting tug boat could be servicing other customers.
- The shore-based Facility might be plumbed to multiple docks, and currently at capacity serving other vessels.

The impact of making fast the barge and shore-based connections are fairly predictable. It is reasonable to make fast and let go hose connections at 30 minutes each, or one-hour for an evolution. Securing a barge would add some additional time. Assuming a one-hour delay, the annual impact to revenue might be $100,000. A vessel operator looking at a ten-year life cycle might value the one-hour delays at $1 million or 50% of the cost of a treatment system installation.

This example does not attempt to quantify the costs for the use of the Facility. Facilities would require personnel to handle the ballast connection and to operate the treatment system. A barge Facility would additionally require barge and tug boat personnel. Facilities might also need to charge fees to recover capital investment and equipment operational costs. The marine vessel might need to pay overtime or call-out fees to personnel to make the ballast connection, as well as additional fuel consumption pumping the ballast water to the deck connection instead of to a relatively lower overboard connection.

The revenue impact of the unplanned delays and routine delays could combined roughly equal the cost of an onboard BWMS. Further, service fees from Facilities are an unknown and could also be considered a risk. A vessel operator might see a risk reduction, and even a cost advantage by installing a BWMS. Some delays could also result from a malfunctioning shipboard system, but the vessel operator would likely see less risk of that because the shipboard system is under the control of the vessel operator.

C) Equipment and operational challenges

Transferring ballast water from a marine vessel to a Facility presents mechanical challenges. These are not unfamiliar to naval architects and marine engineers, as they are quite similar to those faced when transferring liquid petroleum products. In fact, the diligence and control systems required to avoid liquid petroleum spills will be needed to meet higher ballast water discharge standards. A spill of just 1.0 m3 of ballast water would exceed the D-2/Phase 1 discharge standard for even the largest VLCC. A leak from a transfer flange of just 9 liters would exceed the Phase 2 standard.

Marine vessels that must discharge ballast water at high volume flow rates would need to be outfitted in a similar fashion as tank ships. As such they would require high capacity and high head ballast water pumps and large piping to the main deck. It is likely that many vessels would need to increase their electrical generating capacity and power distribution system. Once brought onto the main deck, manifold systems capable of making routine piping connections would be required. Most importantly, vessel operators would require safety and training programs that meet levels that typically are only now seen in the petroleum and offshore industries. To support these tank vessel type operations, receiving terminals would need to be operated in a similar fashion as an oil terminal. In general, this means additional personnel, equipment, procedures, and training.

Marine vessels that discharge ballast water at low volume flow rates would be outfitted in a similar fashion as a fuel oil bunkering station. All marine vessel crews are familiar with such operations. Modifications would be similar as with the high volume flow rate case, except repowering of the electrical plant would be less likely. With some exceptions, bunkering operations may occur only once every 30, 60, or 90 days. These are often an "all hands" event for the vessel's engineering department. The increase of frequency to every cargo load may require an increase in crewing.

D) Logistical challenges

1) Ballast discharge before arrival to reduce time spent at berth

Some vessels may discharge part of their ballast water before arriving at berth so they can complete discharge by the time the cargo is loaded (AQIS 1993a; Oemke 1999; Cohen & Foster 2000; CAPA 2000; Rigby & Taylor 2001a). Alternatively, a ship's ballast water system can be outfitted with pipes and pumps that are large enough to allow the ship to unload ballast water as quickly as it loads cargo (AQIS 1993b). Glosten (2002) and Brown and Caldwell (2007, 2008) identified technical solutions for retrofitting a variety of vessels to allow them to deballast at berth during the time they load cargo. This challenge appears to be resolved.

2) Ballast discharge by lightering vessels

Large tankers that arrive on the U.S. coast carrying crude oil or other liquid cargo may transfer a portion of their cargo to lightering vessels (smaller tankers or barges) in designated anchorages or lightering zones. These lightering vessels often discharge ballast as they load cargo. In many cases, the discharged ballast water is from nearby sites (Cdr. Gary Croot, U.S. Coast Guard, pers. comm. to Andrew Cohen; National Ballast Information Clearinghouse data), and depending on how the regulations are written may not require treatment. In cases where the ballast water is from more distant sites, responses might include offloading ballast water to barges, importing the cargo in different ships, or ballasting lightering vessels with local water. Dames & Moore (1998) suggested that a treatment ship (a vessel designed to receive and treat ballast water from cargo ships) could service deep-drafted high-risk arrivals that need to deballast during approach. Whether this would be generally feasible or cost-effective is unclear.

3) Ballast discharge to reduce draft before arriving at berth

Several studies noted that a ship might also discharge ballast water before arriving at berth to reduce draft in order to cross over shallows or enter a shallow channel (Cohen 1998; Dames & Moore 1998, 1999; Oemke 1999; CAPA 2000, Rigby & Taylor 2001a; California SWRCB; California SLC 2010). However, the frequency of these occurrences has not been quantified, and one possible solution is the same as described above for lightering vessels.

E) Implementation Schedule

A preliminary implementation schedule review indicated that building a network of Facilities could be similar to outfitting the marine vessels subject to the VGP with on board BWMS, assuming that no larger hurdles would exist for on-shore treatment plants as exist for a standard sewage treatment plant. The typical design, permitting and construction timeline for construction of a standard sewage treatment plant is 30 months for plants larger than 10 mgd (≈1580 MT/h) (Robert Bastian, US EPA Office of Water, pers. comm. in email to Dr. Charles Haas, 12/06/10). Most of the onshore ballast water treatment plants needed in the U.S. would probably be smaller than 10 mgd. However, given that a reliance on Facilities requires a network of many Facilities becoming operational simultaneously, failure of the network could result if the construction of a Facility encountered delays from real estate purchase, permitting, or one of many other steps required in the construction of a facility. In addition, shipboard modifications to support either shipboard BWMS or on-shore Facilities will require dry-docking for some marine vessels. Dry dockings, by marine vessel classification society requirement, must be no less than once every five years (ABS SVR 7/2/1-11). In project management terms, the critical path for both onshore and shipboard treatment includes the shipboard work, where the governing factor is the frequency with which the vessel is taken out of service. Thus the time needed to implement either approach might be about the same. A more comprehensive analysis of potential implementation schedules for Facilities is needed.

6.4.4. **Summary comparison of potential features of shipboard BWMS and shore-based Facilities**

Shipboard BWMS and shore-based Facilities differ in important characteristics that may affect efficacy and cost, and that may be favored differently under different regulatory and policy regimes. We summarize some of those important features here (Table 6.8).

Table 6.8. Table 1. Comparison of shipboard and on-shore treatment systems and installations for invasive species control.

Feature	Shipboard treatment	Shore based treatment
General Description	A number of potential treatment systems to eliminate several size classes of organisms . Some of these treatment systems currently appear capable of meeting IMO D-2 and USCG P-I discharge standards .	Facility will be on-shore and similar to that for a water treatment system for prevention of disease. Storage tanks to meet the specific flow rates or other site requirements will be present. The processes will be adopted from water and wastewater treatment and shipboard ballast water management systems.
Number of Installations	Installation will be required for each ship to control invasive species. The number of vessels worldwide requiring the installation of BWMS is estimated to be over 50,000.	Installations will typically number one to several per Port Numbers in the tens-hundreds.
Effluents	Treatment of ballast water from each ship will result in a number of effluents within a Port the size of the ballast tanks of the vessels. The effluent will be dependent upon the type of treatment system for each vessel.	A designated effluent site within a Port. The effluent will be derived from a number of offloading ships and the specific type of treatment at the facility.
Transfers	All treatment systems and associated piping will be contained on-board the vessels.	Large number of transfers from each of the ships in the harbor through long piping.
Receiving habitat	Varying types of receiving water habitats depending upon the location of the individual ship when treated ballast water is discharged.	Receiving water habitats defined by discharge point and its surrounding habitat and currents.

Table 6.8. Table 1. Comparison of shipboard and on-shore treatment systems and installations for invasive species control.

Feature	Shipboard treatment	Shore based treatment
Certification, Regulation, Monitoring and Enforcement*	Equipment to be certified for shipboard use by USC, and type approved by Classification Societies. Vessel inspections, and compliance monitoring will be conducted by USCG and other regulatory agencies. Equipment to be certified for shipboard use, inspected by USCG or other regulatory agency. Large number of vessels to be monitored in this process, estimates range from 50,000 to 70,000 vessels.	NPDES or similar permit for the size of the discharge. One site to be observed and monitored. It is not clear what specifications will be required by USCG. Procedures not yet determined for EPA. Applies to several hundred stationary treatment plants.
Training of personnel	Vessel crew will require training and will be responsible for proper use and maintenance of BWMSs. This process will require additional duties for the crew. Manufacturers are designing the systems for simple operation.	Specialist personnel with specialist experience trained for the operation and maintenance specific to the facility. for the specific installation.

* Compliance procedures for each BWMS not determined yet by either the USCG or EPA.

6.4.5. The path forward

This section has identified the use of Facilities as a promising means to reach higher ballast water treatment standards than may be possible with systems located onboard vessels. The equipment and operational challenges are similar to the transfer of liquid petroleum, and by extension are technically feasible. A preliminary cost analysis indicates that the cost to build and operate Facilities may be less than the cost to outfit all the vessels subject to the VGP with onboard BWMS (Appendix 1).

However, there are systemic hurdles to the implementation of Facilities as an alternative to shipboard BWMS: the regulatory timetables best support installation of BWMS on board marine vessels, and the failure of any Facility in a marine vessel's network of ports may constitute an unacceptable risk to a vessel operator.

It is recommended that the application of the Facility approach be considered for all or at least some marine vessel ballast water management. To that end, the following path ahead is recommended for EPA:

- Perform a comprehensive analysis addressing cost, operations, and safety associated with on shore Facilities compared to shipboard BWMS.
- Survey U.S. marine terminals and fleets to identify vessel-fleet to ports-of-call networks that would most benefit from a Facility approach. Develop a pilot program(s) for one or more of these networks.
- Use the pilot program(s) to rapidly assess challenges associated with Facility networks, and work to develop broadly applicable solutions.
- Develop programs that will relieve the systemic barriers to the implementation of Facility -based ballast water management.
- Based on the pilot program experience, address systemic challenges, support operational solutions as possible, and work to expand Facility networks as widely as practical.

6.5. <u>Approaches other than ballast water treatment</u>

Several approaches other than the treatment of ballast water could help to reduce the risk of biological invasions from ballast water discharges, and contribute to the achievability of discharge standards and permit requirements. While these approaches are often recommended, including by IMO, they are not often required or incentivized in practice. These approaches include ballasting practices to reduce the uptake of organisms, ballast water exchange to reduce the concentration of exotic organisms, reductions in the volume of ballast water discharged in U.S. waters, and management of the rate, pattern or location of ballast water discharge to reduce the risk of establishment. Although the committee's charge questions focused on shipboard treatment, we consider these other approaches because, when used in combination with shipboard treatment, they appear to be capable of achieving a greater level of risk reduction than shipboard treatment alone.

6.5.1. *Managing ballast uptake*

Several studies have recommended various ballasting practices—sometimes referred to as ballast micro-management (Carlton et al. 1995; Oemke 1999; Dames and Moore 1998, 1999; Cohen and Foster 2000), shipboard management measures (Gauthier and Steel 1996), or precautionary management measures (Rigby and Taylor 2001a,b) – to reduce the number of organisms, or the number of harmful or potentially harmful organisms (such as bloom-forming algae and human pathogens found in sewage), that are taken up with ballast water (Table V.B-1 NOTE: Where is this table?). It is suggested that this can be accomplished by managing the time, place and depth of ballasting. Some of these measures have been included in laws, regulations or guidelines, including International Maritime Organization guidelines and the USCG rules implementing the National Invasive Species Act (Table V.B-2 NOTE: Where is this table?). Although some of these regulations or guidelines have been in effect for nearly 20 years, there appear to be no data on levels of compliance and no studies of the effectiveness of any of these measures in reducing the uptake of organisms.

While there may be reasons for skepticism regarding the effectiveness or feasibility of several of these measures (AQIS 1993b; Cohen 1998; Dames and Moore 1998, 1999; Cohen and Foster 2000; Rigby and Taylor 2001b), some could be helpful in meeting stringent standards if vessels
had sufficient incentive to implement them. The effectiveness of alternative ballasting (e.g. locations low in harmful organisms) and deballasting practices (e.g. locations and practices to reduce concentrating propagules) should be quantified. As an example of the former, research has shown that taking up ballast water in areas affected by toxic dinoflagellate blooms, followed by deballasting in another location, can result in distribution of those blooms to previously unaffected areas (Hallegraeff and Bolch 1991). Clearly, such action should be avoided as routine practice, and can also help to meet BWMS standards.

The value of such practices could be evaluated with models using currently available data on organism distributions or by experimental approaches. To the extent these practices would reduce the uptake of organisms, they could be used by vessels to help them meet any discharge standards that might be adopted. From the perspective of overcoming technical limitations on the feasibility of meeting different discharge standards, such practices would allow the adoption of -- and vessel compliance with -- more stringent standards than would otherwise be achievable. Thus, there are valid reasons for the USEPA to consider the potential for employing these practices in combination with ballast water treatment to further reduce the risk of releasing exotic organisms in U.S. waters.

6.5.2. *Mid-ocean exchange*

Mid-ocean ballast water exchange has the potential, in combination with the other approaches discussed here, to further reduce the concentration of exotic organisms (though not necessarily reduce the concentration of all organisms) in ballast discharges. There is general agreement that when properly done, ballast water exchange can reduce the concentration of initially-loaded organisms by about an order of magnitude on average (Minton et al. 2005). It is not however, always possible, especially for coastal voyages

6.5.3. **Reducing or eliminating ballast water discharge volumes**

Invasion risk is positively related to the total number of propagules released in a given time and place. Thus, risk is positively related to the concentration of propagules times the volume of the discharge. Even if the concentration of propagules is unmanaged, reducing discharge volumes will reduce invasion risk in ways that are predictable across taxa (Drake et al. 2005).

Since the 2004 adoption of the IMO Ballast Water Convention, various alternatives to the use of 'conventional' ballast water management systems have been proposed and studied. These emerging alternatives to shipboard BWMSs include concepts and designs for 'ballastless' or 'ballast-free' ships, 'ballast-through' or 'flow-through' ships, the use of 'solid-ballast', and the use of 'freshwater ballast'. In fact, Regulation B-3, of the IMO Convention predicts and allows for the development and future use of such approaches to prevent the transport of invasive species by ships.

Ballastless ship designs are constitute a fundamental paradigm shift in surface vessel design. Rather than increasing the weight of vessels by adding water to ballast tanks, these new designs uses reduced buoyancy to get the ship down to safe operating drafts in the no-cargo condition. For example, the Variable Buoyancy Ship design (Parsons, 1998; Kotinis et al., 2004; Parsons 2010) achieves this by having structural trunks of sufficient volume that extend most of the length of the ship below the "ballast waterline" and then opening these trunks to the sea in the no-cargo condition. When the ship is at speed, the natural pressure difference between the bow and the stern induces flow through the open trunks, resulting in only local water (and associated organisms) within trunks at any point during a voyage. While showing promise, and worthy of further considerations, ballastless ship designs appear feasible only for new vessels being built in the future and may result in an overall increase in vessel biofouling (another significant source of invasive species), if surfaces in open flow-through spaces are more accessible and hospitable than traditional ballast tank surfaces (which are rarely fouled by higher organisms).

Using a similar principle of only local water being onboard a vessel at any one time, other sorts of flow-through ballast systems have also been proposed. These approaches would likely require modifications to the existing ballast systems to actively and continuously pump water in and out of the ballast tanks throughout voyages, resulting in complete tank turnover over in an hour or two.

A return to a historic approach of using solid ballast (commonly iron, cement, gravel or sand) has been discussed recently but may not be feasible or cost effective for most vessels in the modern merchant fleet. Finally, the use of freshwater as ballast has also been proposed, either the onboard production of potable water as ballast for smaller vessels to replace fuel consumption or the transportation of freshwater from one port to another that might have limited supplies of drinking or agricultural water (e.g., Suban et al., 2010).

While many of these alternatives are conceptual at this point, and may be limited to only specific vessels and/or routes, future ballast water management approaches to minimize the risk of invasive species may involve a variety of options and combination approaches.

Marine vessels that carry cargo in bulk, such as oil tankers or dry bulk carriers, cannot generally avoid discharging ballast water in a cargo loading port. Part of the weight of the discharged bulk cargo, typically 50%, must be replaced with ballast water to maintain stability. However, there are other vessels types, such as passenger ships and container ships, that do not experience the same bulk shift in cargo that demands immediate ballast water replacement. These vessels provide opportunities for innovative designs and operational practices that can significantly reduce or even eliminate ballast water discharges in port.

Containership cargo operations may sometimes be balanced between loaded cargo and discharged cargo. Even when not balanced, the weight differential may often be within the margins of the vessel trim and stability requirements. Given increased scrutiny and demands for ballast water exchange, it appears that many operators have been able to reduce or eliminate their discharges through careful operational practices. “"PMSA members all practice ballast water management protocols to reduce or eliminate the risk of introduction of aquatic invasive species in state waters . . . Over 80 percent of vessels hold all ballast water in port to eliminate this risk. Those vessels that must discharge ballast ensure that it is exchanged with mid-ocean water prior to entering coastal waters, dramatically reducing the risk of carrying invasive species” (Pacific Merchant Shipping Agency, National Environmental Coalition on Invasive Species (NECIS))

Totem Ocean Trailers built and are operating two trailer-ships, similar to containerships, that used design trades to eliminate the use of seawater ballast in all cases except emergencies. The ships are a bit wider, and potentially burn some additional fuel to account for their increased size. However, they have eliminated ballast water movements, as well as maintenance efforts associated with salt water piping systems and ballast tanks. Trim corrections are accounted for by shifting ballast water between tanks.

Some vessels only require ballast water to replace fuel oil consumption. A recent research vessel design was able to use the processed effluent from the marine sanitation devices as ballast water. The mass balance between the crew’s gray and black water waste was similar to the amount of ballast water required to account for consumed fuel oil. This approach eliminated traditional sea water ballast from the vessel design.

An industry led initiative, Marine Vessel Environmental Performance (MVeP), provides a numerical score for ballast water environmental soundness. This score accounts for the both the volume and the concentration of the ballast water discharged. Ballast regulations that address not only the concentration of organisms in ballast discharges but also the volume of ballast water discharged could further encourage these developments.

6.5.4. **Temporal and spatial patterns**

Independent of practices of ballast water uptake and total volume of a given discharge (previous sections), operational adjustments that modify the temporal and spatial patterns of ballast water discharge may also reduce the probability that discharged propagules will found a self-sustaining population (Drake et al. 2005). At least for sexually reproducing populations of planktonic species, for a given concentration of a given species in ballast discharge, the greater the volume discharged in a given time at a given location, the greater the probability of population establishment. If a total discharge volume for a given port of call can be broken up in space or time, invasion risk will be lowered. Thus, if a given discharge volume can be spread over space (e.g., as a vessel approaches harbor), be discontinuous in time (with scheduled breaks in discharge), or be discharged in a mixing environment (to dilute the concentration of propagules), the risk of invasion will be lowered (Drake et al. 2005).

For the same reasons, infrastructure modifications within ports that increase the rate and/or magnitude of dilution of discharged propagules would also decrease the risk of population establishment by discharged propagules. If discharges could be made in or piped to locations of greatest mixing within the harbor (e.g., closer to the tidal channels instead of in partially enclosed ship slips), then the rate of diffusion would be more likely to overcome the rate of reproduction. For example, low velocity, low energy propellers, oloid mixers, or other mixing methods are routinely used in sewage treatment plants, industrial applications, and lakes. Such devices could be used in ports to increase the severity of Allee effects and other population hurdles faced by newly discharged propagules to minimize the probability of population establishment.

6.5.5. **Combined approaches**

It may be possible to meet more stringent discharge standards, or otherwise reduce the risk of invasions from ballast water discharges, by combining the approaches discussed in previous sections with either shipboard or onshore treatment. For example, a study by Fisheries and Oceans Canada suggests that conducting a mid-ocean exchange combined with BWMS for Great Lakes bound carriers may result in at least a 10X reduction in density of high risk taxa (Examining a combination treatment strategy: ballast water exchange PLUS treatment, Sarah Bailey, Fisheries and Oceans Canada). After considering the best science and technology now available, the state of Wisconsin is proposing to continue requiring ships to flush their ballast tanks at sea and require oceangoing ships to use BWMS to reduce remaining organisms to a level that meets the international numerical standard. This approach of combining ballast water exchange with shipboard ballast water treatment is targeting an enhanced level of protection for freshwater environments and has also been proposed by Canada in a recent submission to the IMO sub-committee on Bulk Liquids and Gases for consideration.

Each step from ballasting to deballasting, including the choice of procedures and the choice of technologies, contributes to the probability of an invasion occurring (see section on risk assessment). Recognizing and better quantifying the probability associated with each step could better target management efforts and achieve reductions in the overall probability of invasion at lower cost than relying on only BWMS.

6.6. <u>Risk management approaches to reduce invasion risk</u>

6.6.1._**Voyage based risk.assessment to prioritize use of treatment technologies, ballasting and deballasting practices, monitoring efforts, and enforcement**

Most current BWMS (see other sections of this report), and the current and proposed policies that motivated them, are built with a one-size-fits-all approach and designed to be adopted by thousands of ships at some future time. There are defensible reasons for this one-size-fits-all approach, but as we considered above, additional reasons exist to consider more flexible and combination approaches. This is especially true in the face of tight budgets and the constant need to prioritize spending on the most cost effective strategies to reduce invasion risk. Furthermore, invasion risk clearly differs among ships, voyages, and ports in ways that are predictable, and that could provide a basis for guiding the deployment of combinations of technologies and practices now and in the future (Keller et al. 2010). For example, to most cost effectively minimize invasion risk while BWMSs are being phased in, the highest risk ships that conduct the highest risk voyages could be retrofitted first. Likewise, ship-voyage specific risk assessments could guide the schedules for compliance monitoring of the operation and condition of installed water treatment systems.

6.6.2.**Hazard Analysis and Critical Control Points (HACCP)**

A) What is HACCP?
The use of risk assessment for decision-making can be implemented using HACCP. It was developed in the late 1950's to assure adequate food quality for the nascent NASA program, further developed by the Pillsbury Corporation, and ultimately codified by the National Advisory Committee on Microbiological Criteria for Foods in 1997. The ultimate framework consists of a seven-step sequence:

1) Conduct a hazard analysis.
2) Determine the critical control points (CCPs).
3) Establish critical limit(s).
4) Establish a system to monitor control of the CCPs.
5) Establish the corrective action to be taken when monitoring indicates that a particular CCP is not under control.
6) Establish procedures for verification to confirm that the HACCP system is working effectively.
7) Establish documentation concerning all procedures and records appropriate to these principles and their application.

In international trade, these principles are important parts of the international food safety protection system. The development of HACCP broke reliance on the use of testing of the final product as the key determinant of quality, but rather emphasized the importance of understanding and control of each step in a processing system (Sperber and Stier 2009).

B) Basic definitions

Hazard: The hazard under HACCP is the constituent whose risk one is attempting to control.

Critical control point: A critical control point (defined in the food sector) is "any point in the chain of food production from raw materials to finished product where the loss of control could result in unacceptable food safety risk"(Unnevehr and Jensen 1996).

Performance criteria: An important task in the HACCP process is to set performance criteria (critical limits) at each of the critical control points. Based on the final desired quality the minimum performance criteria for each of the CCPs is set, and coupled to this the characteristics of each process that are readily measurable necessary to assure the performance are set. This may be done using experimentation, computational models or a combination of such methods (Notermans, Gallhoff et al. 1994).

C) Application in food and water

HACCP has been applied in the food safety area for 50 years, and in the past decade guidelines and regulations in the US have been written that require an approved HACCP process in a number of applications. For example, FDA has developed a HACCP process applicable to the fish and shellfish industries (21 CFR 123). HACCP has also been widely adopted in the EU, Canada and a number of other developed and developing nations to food safety (Ropkins and Beck 2000).

Havelaar (1994) was one of the first to note that the drinking water supply/treatment and distribution chain has a formal analogy to the food supply/processing/transport/sale chain, and therefore that HACCP would be applicable. However, in effect, the development of the US surface water treatment rule under the Safe Drinking Water Act (40 CFR 141-142) and subsequent amendments incorporate a HACCP-like process. Under this framework, an implicitly acceptable level of viruses and protozoa in treated water was defined. Based on this, specific processes operated under certain conditions (e.g., filter effluent turbidity for granular filters) were “credited” with certain removal efficiencies, and a sufficient number of removal credits needed to be in place depending on an initial program of monitoring of the microbial quality of the supply itself. This approach (of a regulation by treatment technique) is chosen when it is not “economically or technically feasible to set an MCL (added: maximum concentration level)” (Safe Drinking Water Act section 1412(b)(7)(A))

D) How HACCP might be applied to ballast water management

Vessel- and shore-based approaches differ in a number of characteristics that will affect the HACCP process: the number and size of installations, the location and number of effluent streams and the receiving habitats, the transfer of ballast water, the regulatory agencies and the training of personnel (Table 6.8). The implementation of a HACCP program will have to take into account the regulatory agency and their scope of enforcement, the training of personnel and the operational factors of each type of treatment. The next paragraphs provide general examples of how HACCP could be applied via the following steps:

- Enumerate critical control points (which might include each particular treatment process as well as the method and type of intake water used)
- Determine the needed logs reduction in totality of the entire treatment system given the nature of the intake water (to achieve D-2, 10x D-2, etc.), and allocate these reductions amongst individual treatment processes.
- Given criteria in the discharged treated ballast water (e.g., D-2, 10x D-2, etc), determine the minimum performance criteria for each treatment process, as well as criteria that determine whether or not particular intake water might be suitable. Note that these performance criteria should be based on easily measurable parameters that can be used for operational control. Research may be needed to determine relationships for each process between such surrogate parameters and removal of each of the size classes of organisms.
- A given ship having a set of processes with designated removal credits would only be allowed to take in ballast water that does not exceed the capacity of the controlled process train to meet the discharge criteria under the controlled operation.
- A QA process needs to be set up for periodic validation and auditing (for example by a 3rd party organization), and an operational procedure needs to be developed indicating what corrective action is to be taken for a particular installed process should a surrogate parameter be outside acceptable limits (this might be holding for additional time, recirculating for additional treatment, or some other measure).
- A blind certification testing procedure for the treatment products can be added as part of the HACCP. This type of process will ensure that the testing laboratory is not biased.
- Control points also could be identified for the various steps in the transfer of an invasive species to a new habitat. This overall process is illustrated in Figure 6.2.

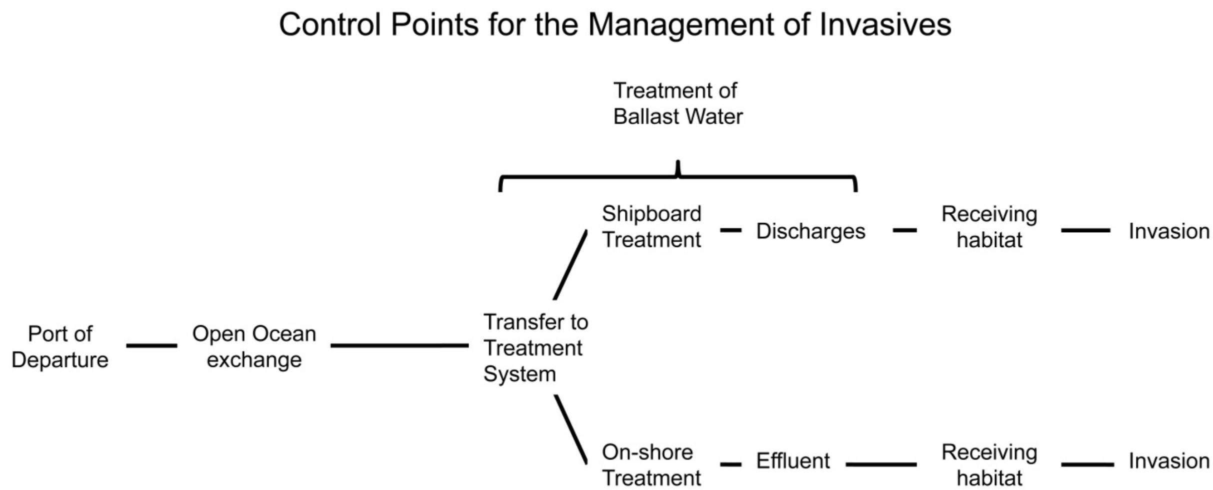


Figure 6.2. Some control points for the control of invasives. Each of the processes may have imbedded control points.

Section 6.5 provides approaches for estimating risk and managing invasives in detail. In this paragraph we provide two examples. First the characteristics of the port of origin can be included in the consideration of the types of propagules likely to be included in the ballast water. Known hazards from particular ports could be identified and the protocol for the control process modified for those ports. Open ocean (or water) exchange is a means of reducing the number of propagules from the original port. Sea conditions or other factors may preclude an exchange. The control process may require modification to allow for this contingency. Next there is transfer from the ballast tanks to the treatment system, which could be on-board or on-shore. For both types of treatment, multiple control points can be identified that can be part of the HACCP process. A diagram such as Figure 6.2) can be particularly useful in establishing control points. The role of sea chests, filter systems, oxidizing systems and plumbing can be identified. On-board vs. on-shore treatment facilities will differ in the number and location of discharge points, which would also be taken into account in the HACCP process.

Likely outside of an engineering-based HACCP, but part of an overall strategy, is the consideration of the receiving waters for the ballast water and the types of habitat. Receiving habitats that are similar to those of the original port are likely to provide more opportunity for the establishment of an invasive species or pathogen. This information may be useful in establishing a site-specific treatment recommendation. These habitats could also be monitored as part of an overall plan for reducing the likelihood of successful invasion.

6.7. Summary and recommendations

6.7.1. Principal limitations of available data and protocols

- Data are not sufficiently compatable to compare rigorously across ballast water treatment systems because standard protocols for testing ballast water treatment systems have been lackin. ETV protocols will improve this situation.

- No international requirement exists to report failures in type approval testing. On the basis of typically reported results, therefore, it is impossible to draw reliable conclusions about the consistency or reliability of BWMS.

- The important size classes ≤ 10 µm previously have been ignored in developing guidelines and standards.

- Clear definitions and direct methods to enumerate viable organisms in the specified size classes at low concentrations are missing for some size classes and indicator organisms and logistically problematic for all size classes, especially nonculturable bacteria, viruses, and resting stages of many other taxa.

6.7.2. **Alternatives to shipboard treatment of ballast water**

- Data on the effectiveness of practices and technologies other than shipboard ballast water treatment systems are woefully inadequate because insufficient attention has been given to integrated sets of practices and technologies including (1) managing ballast uptake to reduce presence of invasives, (2) reducing invasion risk from ballast discharge through operational adjustments and changes in ship design to reduce or eliminate need for ballast water, (3) development of voyage-based risk assessments and / or HACCP principles, and (4) options for on-shore treatment.

- Onshore treatment of ballast water is technically feasible, and screening-level economic estimates suggest that it is at least as economically feasible as shipboard treatment. Equipment, operational, and logistical challenges will need to be overcome and facilities designed to minimize impact on vessel revenue.

- Onshore treatment is likely to be safer, more reliable and more adaptable than shipboard treatment.

- The effort and cost of monitoring and enforcement needed to achieve a given level of compliance is likely to be much less for a relatively small number of on-shore treatment plants compared to approximately 300 times as many shipboard plants.

- The current regulatory framework provides little incentive for development of onshore treatment facilities.

6.7.3. **To overcome present limitations, we recommend that:**

- Testing of BWMSs in a research and development mode should be distinct from testing fro type approval.

- Type approval testing should be conducted by a party independent from the manufacturer with appropriate, established credentials, approved by EPA/USCG.

- Reported results from type approval testing of BWMS should include failures as well as successes during testing so that the reliability of systems can be judged. This would be aided by the adoption of a transparent international standard format for reporting, including specification of QAQC protocols.

- Infectious viruses should not be included in standards for BTWSs until new technology becomes commercially available that reliably distinguishes infectious from non-infectious agents.

- Complete test results for ballast water treatment systems, including failures, be reported and considered in certification decisions.

- Testing protocols should be internationally comparable and, ideally, applied across the full gradient of environmental conditions represented by the Earth's ports, and use natural sources of water, including natural salinity, DOC, etc.

- Protist-sized organisms should be included in ballast water standards, and therefore in protocols to assess the performance of ballast water treatment systems.

- Testing protocols diverge from those recommended by the ETV report for the components highlighted in Table 6.4.

- Protocols be developed to identify suitable standard test organisms surrogate taxa and surrogate parameters to complement or replace metrics that are logistically difficult or infeasible for estimating directly the concentration of living organisms.

- Use of representative "indicator" taxa (toxic strains of *Vibrio cholerae*; *Escherichia coli*; intestinal enterococci) should continue to be used as a sound approach to assess BWMSs for effective removal of harmful bacteria. These estimates will be improved when reliable techniques become available to account for active, nonculturable cells as well as culturable cells.

- Laboratory bench (small scale) tests should be used as a sound first step in assessing BWMS performance because they enable controlled testing over a full range of environmental and biological conditions and help to identify limitations or critical flaws in the system design while minimizing logistical difficulties, expense, and risks. As a second step, tests should be conducted in mesocosms (intermediate scale) because they enable testing under more realistic conditions in checking treatment performance prior to full-scale, land-based testing.

- As a critical part of the BWMSs, EPA should develop metrics appropriate for compliance monitoring and enforcement as soon as possible.

- Combinations of practices and technologies should be considered as potentially more effective and potentially more cost-effective approaches than reliance on one ballast water treatment technology. For example, ship-specific risk assessments (based on the environment and organisms present in previous ports of call) could be used to help prioritize the use of risk management practices and technologies, as well the targeting of compliance and enforcement efforts.

- EPA should encourage the development of an ISO standard for type approval testing of BWMS

- EPA should conduct a comprehensive analysis addressing cost, operations, and safety associated with on-shore Facilities, identify vessel-fleet to ports-of-call networks that would most benefit from a Facility approach, and develop a pilot program(s) for one or more of these networks to assess challenges and develop solutions.

- EPA should develop programs that will relieve the systemic barriers to the implementation of Facility-based ballast water management.

- EPA should conduct further study of the efficacy and costs of onshore treatment. If the evidence indicates that onshore treatment is both economically and logistically feasible and is more effective than shipboard treatment systems, it should be used as the basis for assessing the ability of available technologies to remove, kill, or inactivate living organisms to meet a given discharge standard. In other words, onshore treatment may enable ballast water discharges to meet a stricter standard.

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APPENDIX A: Information on BWMS compiled by EPA

Table A1-1. Reports that discuss onshore treatments

Report	Discussion	Conclusions
Pollutech 1992	Compares and ranks various shipboard and onshore treatment approaches.	Onshore ranks 2nd out of 24 options, ahead of all but one shipboard system.
3AQIS 1993a	Compares shipboard, land-based and treatment ship approaches.	Land-based and treatment ship are cheaper and more effective than shipboard.
AQIS 1993b	Briefly discusses treatment ship and land-based treatment.	Onshore treatment is unlikely except in special circumstances.
Aquatic Sciences 1996	Compares shipboard, treatment ship, land-based and external source treatment.	Onshore is technically feasible and the most effective and cheapest approach.
NRC 1996	Briefly discusses advantages and disadvantages of onshore treatment.	Onshore remains an option.
Gauthier & Steel 1996	Mentions shipboard, treatment ship and land-based approaches.	Onshore is considered a poor option.
Victoria ENRC 1997	Briefly discusses onshore treatment.	Onshore is probably too costly at a large scale; may be viable at a smaller scale.
Greenman et al. 1997	Student report commissioned by the U.S. Coast Guard, largely reprising AQIS 1993a.	
Cohen 1998	Briefly discusses advantages and disadvantages of onshore treatment.	
Reeves 1998, 1999	Briefly discusses onshore treatment.	Lists onshore as an alternative.
Oemke 1999	Briefly discusses advantages and disadvantages of onshore treatment.	Onshore is feasible for some parts of the industry, such as VLCCs.
Dames & Moore 1998, 1999	Briefly discusses onshore treatment.	Onshore may be good option at oil export terminals with oil stripping plants.
Cohen & Foster 2000	Briefly discusses advantages and disadvantages of onshore treatment.	
CAPA 2000	EPA-funded study estimates the cost of onshore treatment for California.	Onshore is technically feasible.
Rigby & Taylor 2001a,b	Briefly discusses onshore treatment.	Cost, availability, quality control may prevent onshore development, but it might work for tankers that discharge oily ballast to onshore facilities.
US EPA 2001	Briefly mentions onshore treatment.	
California SWRCB 2002	Briefly discusses onshore treatment.	Onshore is an attractive option, at least for some parts of the industry.
Glosten 2002	Estimates upper-bound retrofit costs to discharge ballast to onshore facilities.	
NSF 2003	Mentions shipboard, onshore and operational options for the longer term.	Shipboard seems the most challenging approach.

Table A1-1. Reports that discuss onshore treatments

Report	Discussion	Conclusions
Brown & Caldwell 2007, 2008	Develops designs and estimates costs for onshore treatment at Milwaukee.	Onshore is feasible; treatment ship is cheaper than land-based.
California SLC 2009, 2010	Briefly discusses advantages and disadvantages of onshore treatment.	Onshore might be suitable for terminals with regular vessel calls such as cruise ships, or for the Port of Milwaukee.

APPENDIX B: FURTHER ANALYSES OF ONSHORE TREATMENT FACILITIES

This appendix was provided by Andrew Cohen and reviewed by two members of the Panel. [NOTE: If other Panel members wish to be listed as authors, this will be done.]

A. Literature Review of Onshore Treatment Studies

Table A1-1 summarizes the few analyses and several brief commentaries on onshore treatment that we found in the published and gray literature.

Four studies compared the effectiveness or costs of onshore and shipboard ballast water treatment. In a study for the Canadian Coast Guard, Pollutech (1992) scored and ranked a variety of ballast water management approaches for vessels entering the Great Lakes, including ballast water exchange and several shipboard and onshore treatments, in terms of effectiveness, feasibility, maintenance and operations, environmental acceptability, cost, safety and monitoring. On-shore treatment with discharge to a sanitary sewer (the only onshore treatment scenario analyzed) ranked second out of 24 treatment and management approaches analyzed in the report.

AQIS (1993a) developed conceptual designs and cost estimates to compare shipboard, land-based and treatment ship approaches to treating the ballast water discharged from 140,000-ton bulk carriers carrying 45,000 MT of ballast water with a maximum ballast pumping rate of 4,000 MT/h, and an annual discharge of 500,000 MT. The shipboard system that was analyzed consisted of a 50-µm in-line strainer employed during ballasting, plus the installation of high-level ballast tank offtake pipes to reduce the discharge of ballast sediments and settled cysts or spore stages. The cost of pump upgrades that might be needed to address head loss from the strainers was not included. The land-based facility was designed to handle the discharge from three bulk carriers per week and included 52,000 MT storage capacity with coagulation, flocculation, granular filtration and UV disinfection at a maximum treatment rate of 830 MT/h, and thickening, dewatering and land-fill disposal of residual solids. The cost of land acquisition and the cost of pipelines needed to carry ballast water from the berths to the treatment plant were not included. The treatment ship alternative was based on converting a used 12,500 DWT bulk carrier and installing 4,000 MT of storage capacity and a treatment system similar to the land-based system but using pressurized granular filters with a maximum treatment rate of 4,000 MT/h. The cost estimates, including the cost of retrofitting cargo ships with pipe and pump upgrades needed for discharging to an onshore treatment plant[1], are summarized in Table A1-2. Based on the annualized cost per MT of ballast water, treatment in a land-based facility ($0.23-$0.35/MT) is less than half to about two-thirds of the cost of treatment in a shipboard plant ($0.53/MT). Treatment costs per MT are greater for a treatment ship ($0.46-$0.70/MT) than for a

[1] Based on the estimated retrofit cost for a large bulk carrier (AQIS 1993a at p. 73) of $204,084 in June 2010 US dollars.

land-based facility, and may be somewhat more or somewhat less expensive than for a shipboard system, depending on the utilization rate of the treatment ship (Table A1-2).

Table A1-2. Treatment cost estimates for shipboard, land-based and treatment ship approaches - single port scenario (AQIS 1993a). The figures have been adjusted to June 1, 2010 US dollars and annualized as described in Appendix 1B. The number of ships is calculated as the number of bulk carriers (each discharging 500,000 MT/y) needed to discharge the stated annual treatment volume to the plant.

Treatment System	Number of Ships	Capital Costs Storage	Treatment	Ship Retrofit	Operating Cost/MT	Annualized Cost/MT
Shipboard [1]	1	0	2,041,000	0	0.082	0.529
Land-based [2]	11	3,061,000	6,123,000	2,245,000	0.092	0.227
Land-based [3]	11	6,123,000	6,123,000	2,245,000	0.092	0.263
Land-based [4]	11	3,061,000	16,330,000	2,245,000	0.092	0.348
Treatment ship [5]	14	8,674,000	12,755,000	2,857,000	0.422	0.700
Treatment ship [6]	23	8,674,000	12,755,000	4,694,000	0.276	0.458

[1] Treating 500,000 MT/y, or about 1 voyage/month.
[2] Treating 5,500,000 MT/y, with 52,000 MT storage in earthen basins and 830 MT/h treatment rate.
[3] Treating 5,500,000 MT/y, with 52,000 MT storage in steel tanks and 830 MT/h treatment rate.
[4] Treating 5,500,000 MT/y, with 4,000 MT storage in steel tanks and 4,000 MT/h treatment rate.
[5] Treating ≈3 ships/week (described as 40% utilization in AQIS 1993a), or 7,000,000 MT/y.
[6] Treating ≈5 ships/week (described as 70% utilization in AQIS 1993a), or 11,500,000 MT/y.

AQIS (1993a) also developed a scenario for onshore treatment of all the ballast water discharged in Australia (estimated at 66 million MT/y from at least 1,000 distinct ships) that included 3 treatment ships and 18 land-based treatment plants located in Australia’s major ports, along with 16 barges to transport ballast water collected at smaller ports. The estimated total costs based on these assumptions are shown in Table A1-3. In this scenario the average annual ballast water discharge per ship is much smaller than in the single port scenario of Table A1-2, and the annualized costs per 1,000 MT are therefore larger. In this countrywide scenario, total shipboard treatment costs are about 4.4 times the total treatment costs onshore.

Table A1-3. Treatment cost estimates for shipboard and onshore approaches - Australia-wide scenario (AQIS 1993a). The figures have been adjusted to June 2010 US dollars and annualized as described in Appendix 1B.

Approach	Capital Costs: Onshore Treatment Plants	Treatment Ships	Barges	Shipboard Treatment or Retrofit	Operating Cost /1000 MT	Total Annualized Cost
Shipboard	–	–	–	2,041,000,000	82	228,900,000
Onshore	183,700,000	61,225,000	81,630,000	204,100,000	102	51,740,000

The study concluded that "land-based or port-based [=treatment ship] facilities are more economic and effective than numerous ship-board plants." In these estimates, some significant costs (pipelines to transport ballast water from berths to treatment plants, and land costs) were not included in the onshore alternatives which reduced their estimated total cost relative to the shipboard alternative. On the other hand, the onshore treatment approach (using granular filtration with coagulation and flocculation followed by UV disinfection) would treat ballast water to a substantially higher standard than the shipboard alternative (using only a 50 µm strainer with no disinfection); and for the single-port scenario, basing the analysis on large bulk carriers, which typically discharge the largest volumes of ballast water of the vessels using Australia's ports (Table 4.1 in AQIS 1993a), greatly favored shipboard treatment. The estimates are also somewhat sensitive to other factors, including the assumed utilization rates for the onshore systems, and the interest rate used to annualize costs.

In another study conducted for the Canadian Coast Guard, Aquatic Sciences (1996) considered onshore treatment alternatives (referred to as "pump off options") for Great Lakes shipping and found them to be "technically feasible" and to "undoubtedly offer the best assurance of prevention of unwanted introductions." The report further found that when installed onshore, "treatment options could have a more practical and enforceable application" than in shipboard installations, and concluded that "ship board treatment of ballast water appears to be logistically, economically, and particularly from the aspect of control, the least attractive method of ballast water treatment." The report estimated that treatment ships could be provided at key ports throughout the Great Lakes to receive discharged ballast water and heat it to >65°C at an annualized cost of around $17 to $51 million, or alternatively a single treatment ship could operate at a site en route to the Great Lakes to treat all incoming ballast water at an annualized cost of $2.7-2.8 million. Retrofitting costs to enable ships to discharge their ballast water to treatment ships were estimated at approximately $40,000 to over $200,000 per ship.[2]

California's State Water Resources Control Board (California SWRCB 2002) qualitatively evaluated onshore treatment and ten shipboard treatment alternatives for effectiveness, safety, and environmental acceptability. Onshore treatment was the only approach rated acceptable in all three categories. There were reservations or unresolved questions about the effectiveness of all shipboard alternatives, about the safety of 80% of the shipboard alternatives, and about the environmental acceptability of 90% of the shipboard alternatives.

In each of these studies, onshore treatment was judged to be as effective or more effective, and generally cheaper, than shipboard treatment. As noted, there are limitations to these studies and grounds for criticism, however the first three appear to be the most detailed comparisons of onshore and shipboard treatment approaches available.

The other comparisons of onshore and shipboard treatment in the literature consist of lists or brief discussions of their relative merits. These reports variously conclude that onshore treatment is probably a superior or probably an inferior option compared to shipboard treatment, or that onshore treatment is suitable for a particular part of the cargo fleet (Table A1-1), but none

[2] The costs cited in this paragraph were adjusted to June 1, 2010 US dollars as described in Appendix 1B.

provide analysis or data to support these conclusions.

Two studies (in addition to AQIS (1993a) and Aquatic Sciences (1996), discussed above) provide conceptual designs and cost estimates for onshore treatment for specific regions. CAPA (2000), an EPA-funded study conducted for the California Association of Port Authorities, developed conceptual designs and cost estimates for constructing and operating ballast water treatment plants at each cargo port in California. These plans and estimates include pipelines from berths to plants; storage tanks; coagulation, flocculation, filtration and UV disinfection; thickening, dewatering and landfill disposal of residual solids; and discharge of effluent through an outfall pipeline. These estimates did not include land costs, permitting, seismic evaluation, or costs to retrofit vessels to enable them to discharge ballast water to an onshore facility. The study concluded that onshore treatment would be technically and operationally feasible, though there could be delays to vessels in some circumstances. The estimated costs are shown in Table A1-4.

Table A1-4. Cost estimates for onshore treatment in California (CAPA 2000). The figures have been adjusted to June 1, 2010 US dollars and annualized as described in Appendix 1B.

	— — — Capital Costs — — —					
Port	**Pipelines**	**Storage Tanks**	**Treatment Plant**	**Outfall**	**Annual O&M**	**Annualized Costs**
Hueneme [1]	1,325,000	69,000	0	125,500	0	98,850
Humboldt Bay	15,900,000	5,020,000	2,235,000	125,500	188,000	1,702,000
Long Beach	35,910,000	6,400,000	2,790,000	125,500	280,000	3,222,000
Los Angeles	33,920,000	25,600,000	2,790,000	125,500	280,000	4,342,000
Oakland	19,880,000	4,770,000	2,235,000	125,500	188.000	1,945,000
Redwood City	1,990,000	5,400,000	2,047,000	125,500	178,700	800,000
Richmond	7,290,000	4,270,000	2,047,000	125,500	178,700	1,072,000
Sacramento	1,723,000	6,023,000	2,047,000	125,500	178,700	824,000
San Diego	11,660,000	3,900,000	2,047,000	125,500	178,700	1,332,000
San Francisco	10,600,000	7,900,000	2,235,000	125,500	188,000	1,545,000
Stockton	6,760,000	6,900,000	2,047,000	125,500	178,700	1,209,000
California	146,950,000	76,235,000	22,510,000	1,380,000	2,018,000	18,091,000

[1] CAPA (2000) concluded that building a treatment plant at Port Hueneme made no sense because so little ballast was discharged there (<2 MT/d), and that instead the ballast water could be "discharged to the sewer, reballasted to an outgoing ship, taken to another port for treatment,...transported by a separate vessel for discharge at sea" or batch treated with chlorine. The report's estimate includes pipelines, storage and outfall costs for this site, but not treatment plant costs.

Brown and Caldwell (2007, 2008) developed designs and cost estimates for land-based and treatment ship approaches to treating ballast discharges from oceangoing ships arriving at the Port of Milwaukee. The first report assessed four land-based treatment systems:

- 100-µm screening followed by UV treatment;
- coarse screening followed by ozonation;

- 500-µm screening followed by membrane filtration to remove particles >0.1 µm;
- 500-µm screening followed by hydrodynamic cavitation.

These were each analyzed along with two systems for transferring and storing the discharged ballast water: discharge at berths into pipelines that carry the water to land-based storage tanks and a treatment plant; and discharge to a barge that stores the water and carries it to a land-based treatment plant. Design criteria assumed 85 ship arrivals during the eight months that the St. Lawrence Seaway is open each year, and a system capable of receiving ballast water at 680 MT/h, with storage capacity of 1,900 MT, and treatment at 80 MT/h. Estimated costs are shown in Table A1-5. The report concluded that all four treatment systems and both transport/storage systems are feasible, with UV treatment and hydrodynamic cavitation having the most promise for treating viruses (Brown and Caldwell 2007). The second report (Brown and Caldwell 2008) developed a design and cost estimate for retrofitting a barge to serve as a treatment ship, which would collect, store and treat ballast water. Treatment included a cloth media disk filter with a nominal pore size of 10 µm, and UV disinfection at an estimated minimum dose of 30 $mJWs/cm^2$. The design criteria for this analysis included the capacity to receive ballast discharges at 2,300 MT/h, storage of 10,000 MT, and treatment at 230 MT/h, which is around 3 times the flow rates and 5 times the storage required in the first report. The cost estimates for the eight land-based treatment alternatives analyzed in the first report, adjusted to meet the more demanding design criteria used in the second report, plus the cost estimates for the treatment ship in the second report, are shown in Table A1-6.

Table A1-5. Cost estimates for onshore treatment for oceangoing ships at the Port of Milwaukee (Brown and Caldwell 2007). The figures have been adjusted to June 1, 2010 US dollars and annualized as described in Appendix 1B.

Treatment (Transport) [1]	— — Capital Costs — —			Annual O&M	Annualized Costs
	Pipelines [2]	Storage	Treatment		
100-µm screening & UV (pipelines)	2,973,000	1,252,000	584,000	14,000	400,000
Ozone (pipelines)	2,973,000	1,252,000	835,000	9,800	416,000
0.1-µm membrane filter (pipelines)	2,973,000	1,252,000	1,043,000	20,000	443,000
Hydrodynamic cavitation (pipelines)	2,973,000	1,252,000	2,608,000	20,900	569,000
100-µm screening & UV (barge) [3]	261,000	522,000	584,000	369,000	479,000
Ozone (barge) [3]	261,000	522,000	835,000	365,000	495,000
0.1-µm membrane filter (barge) [3]	261,000	522,000	1,043,000	375,000	522,000
Hydrodynamic cavitation (barge) [3]	261,000	522,000	2,608,000	376,000	648,000

[1] Design criteria are: maximum ballast discharge of 680 MT/h, storage of 1,900 MT, and treatment rate of 80 MT/h; "(pipelines)" refers to discharge of ballast water at berths into pipelines connecting to the treatment plant; "(barge)" refers to discharge to a barge to transport the ballast water to the treatment plant.
[2] Includes collection pumps, pipelines, a lift station and coarse screening.
[3] "Storage" refers to barge purchase and modification to use for ballast water transfer and storage, exclusive of the treatment system.

Table A1-6. Cost estimates for onshore treatment for oceangoing ships at the Port of Milwaukee (Brown and Caldwell 2007, 2008). The figures for the eight alternatives analyzed in Brown and Caldwell (2007) adjusted to meet the design criteria of Brown and Caldwell (2008) as described in Appendix 1C. All figures have been adjusted to June 1, 2010 US dollars and annualized as described in Appendix 1B.

	— — Capital Costs — —				
Treatment (Transport) [1]	**Pipelines [2]**	**Storage**	**Treatment**	**Annual O&M**	**Annualized Costs**
100-µm screening & UV (pipelines)	5,385,000	3,547,000	1,670,000	14,000	865,000
Ozone (pipelines)	5,385,000	3,547,000	2,384,000	9,800	918,000
0.1-µm membrane filter (pipelines)	5,385,000	3,547,000	2,980,000	20,000	976, 000
Hydrodynamic cavitation (pipelines)	5,385,000	3,547,000	7,422,000	20,900	1,330, 000
100-µm screening & UV (barge) [3]	795,000	1,043,000	1,669,000	369,000	651, 000
Ozone (barge) [3]	795,000	1,043,000	2,384,000	365,000	704, 000
0.1-µm membrane filter (barge) [3]	795,000	1,043,000	2,980,000	375,000	762, 000
Hydrodynamic cavitation (barge) [3]	795,000	1,043,000	7,421,623	376,000	1,120,000
10-µm filter & UV (treatment ship) [3]	0	2,695,000	808,854	519,000	800,000

[1] Design criteria are: maximum ballast discharge of 2,300 MT/h, storage of 10,000 MT, and treatment rate of 230 MT/h; "(pipelines)" refers to discharge of ballast water at berths into pipelines connecting to the treatment plant; "(barge)" refers to discharge to a barge to transport the ballast water to the treatment plant.
[2] Includes collection pumps, pipelines, a lift station and coarse screening.
[3] "Storage" refers to barge purchase and modification to use for ballast water transfer and storage or as treatment ship, exclusive of the treatment system.

Besides the need for facilities to receive and transport ballast water from ships, store it and treat it, ships must be modified so they can safely and rapidly discharge ballast water to onshore facilities. There have been several estimates of these ship retrofit/modification costs (Table A1-7), which require modifications in a ship's pipe system and may require the installation of larger ballast pumps (in order to raise the water to deck level, and/or to discharge it quickly enough). These costs vary between different types and sizes of ships, with cost estimates ranging from around $15,000 to $540,000 for container ships (Pollutech 1992; Glosten 2002), from around $15,000 to $500,000 for bulkers (Pollutech 1992; CAPA 2000), and from considerably less than $140,000 to around $2.3 million for tankers (Victoria ENRC 1997; Glosten 2002) (Fig. A1-2). Most of these estimates specifically include the replacement of existing pumps with more powerful pumps where needed (AQIS 1993a; Aquatic Sciences 1996; Dames & Moore 1998; CAPA 2000; Glosten 2002[3]; Brown and Caldwell 2008[4]). The estimated cost to outfit a new ship would be less than the cost to retrofit a comparable existing ship (AQIS 1993b), perhaps by as much as an order of magnitude (CAPA 2000). Some of the reports provide little or no explanation or supporting data for the retrofit/modification estimates (Pollutech 1992; AQIS 1993a; Aquatic Sciences 1996; Dames & Moore 1998). Victoria ENRC (1997) provided a

[3] Glosten (2002) designed the pumps and pipe systems to be large enough to enable ships to deballast completely at berth during a typical cargo loading period.
[4] Brown and Caldwell (2008) found, based on dynamic head vs. flow curves for the pump and pipe systems, that the Great Lakes bulk carriers they analyzed would not need larger ballast pumps—that is, with their existing pumps the ships could fully deballast while at berth during the time it takes to load cargo.

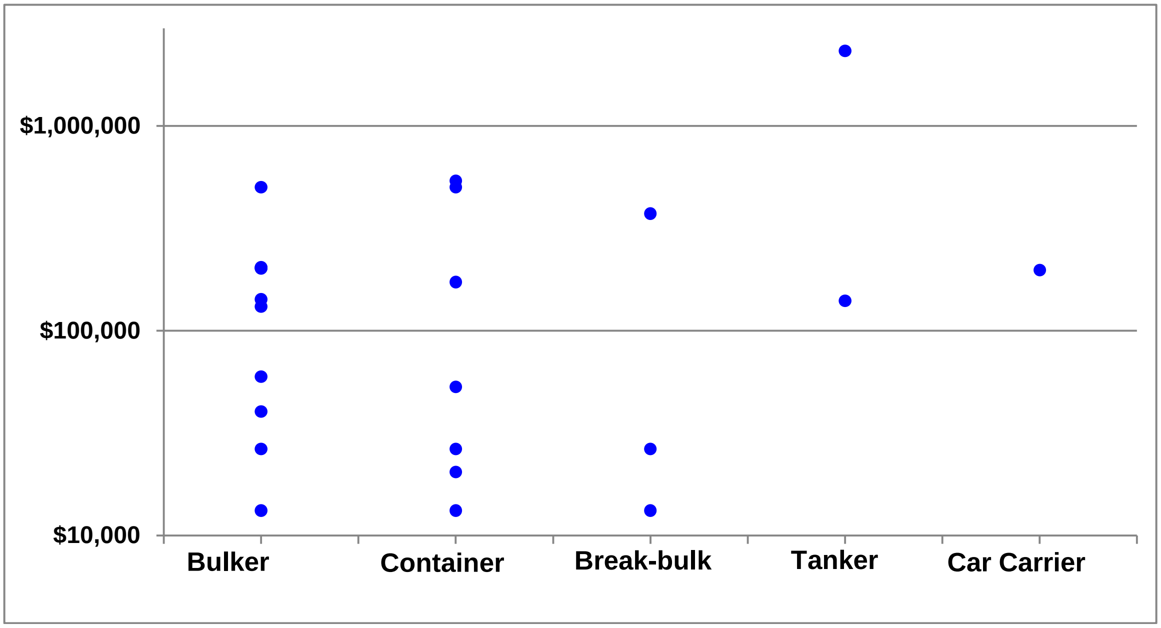
materials list for a bulk carrier, and noted that a tanker "with its ballast lines running on deck would have a considerable lower installation cost." CAPA (2000) provided a cost-breakdown for modifying a bulk carrier, and stated that modifying a tanker would generally cost more.

Table A1-7. Cost estimates for retrofitting ships to discharge ballast water to a treatment facility. The figures have been adjusted to June 1, 2010 US dollars as described in Appendix 1B. In the parentheses following the ship type, length is given in feet, size in deadweight tons (DWT), ballast water capacity in metric tons (MT), and maximum ballast discharge rate in metric tons per hour (MT/h), where these data are available.

Ship Type	Capital Cost	Report
Great Lakes bulker, break-bulk or container	$13,200–26,500	Pollutech 1992
Small container	$20,400	AQIS 1993a
Large bulker (140,000 DWT; 45,000 MT; 4,000 MT/h)	$204,000	AQIS 1993a
Great Lakes bulker	$40,400–202,00	Aquatic Sciences 1996
Handysize bulker (520'; 22,000 DWT)	$142,000	Victoria ENRC 1997
Container	$53,200-173,000	Dames & Moore 1998 [1]
Container or bulker (1,000 MT/h)	$502,000	CAPA 2000
Tanker (869'; 123,000 DWT; 75,850 MT; 6,400 MT/h)	$2,3230,000	Glosten 2002
Bulker (735'; 67,550 DWT; 35,000 MT; 2,600 MT/h)	$131,000	Glosten 2002
Break-bulk (644'; 40,300 DWT; 26,850 MT; 3,000 MT/h)	$373,000	Glosten 2002
Container (906'; 65,480 DWT; 19,670 MT; 2,000 MT/h)	$540,000	Glosten 2002
Car carrier (570'; 13,847 DWT; 6,600 MT; 550 MT/h)	$198,000	Glosten 2002
Bulker (469'; 5,700 MT; 570 MT/h)	$60,000	Brown and Caldwell 2008
Bulker (722'; 18,000 MT; 2,300 MT/h)	$203,000	Brown and Caldwell 2008

[1] Estimate developed by the Pacific Merchant Shipping Association.

Figure A1-2. Cost estimates for retrofitting ships to discharge ballast water to a treatment facility. The figures have been adjusted to June 2010 US dollars as described in Appendix 1B. Some estimates apply to more than one ship type, and appear in more than one column in the figure.



Glosten (2002) and Brown and Caldwell (2008) provide the most detailed estimates. Glosten (2002) estimated ship retrofit/modification costs for five ships representing common vessel types in Puget Sound (Table A1-7). These modifications were designed to "allow ballast transfer with minimal disruption to current operations" including sizing them to allow ships to deballast completely at berth during the time needed to complete cargo loading, eliminating the need to start deballasting before arriving at berth. To represent each vessel type, the authors selected ships that "had ballast systems with capacities on the upper end of vessels that call on Puget Sound to attempt to establish an upper-bound on retrofitting costs." In selecting pipe sizing and other design elements "every attempt was made to capture an upper bound on the modification costs associated with each vessel type surveyed," including the installation of "a completely new piping system to provide the ability to fill and empty each ballast tank separately." Notably, this new piping system was included in the tanker estimate even though it is not needed on crude oil tankers, the type of tanker analyzed where "a simpler, lower-cost solution" exists. It was included because it might be needed on some other ships (i.e. product tankers) in the same general category, and this produced by far the highest cost estimate in the study.[5] The modifications were also designed to allow ballast water transfer in either direction between a ship and an onshore facility (either onto or off a ship),[6] which in some cases may raise the cost over what is needed to only discharge ballast water to onshore facilities.

[5] Consistent with the study's aim of quantifying "the capital cost required to provide the maximum capability in a ballast transfer system, to represent a maximum capital investment" for each vessel category (Glosten 2002).
[6] This ability was included to accommodate the possibility of loading "clean" ballast, an approach that is not considered to be onshore treatment in this report.

Brown and Caldwell (2008) provided analyses, conceptual designs, drawings and cost estimates for modifying two sizes of ocean-going bulk carriers serving the Great Lakes, based on a smaller, actual ship and a larger hypothetical ship (Table A1-7). These designs were also sized to allow the ship to initiate and complete deballasting at berth during cargo loading.

In addition to discussions of onshore treatment in reports, the potential for treating ballast discharges onshore has been recognized in laws, regulations, guidelines and treaty conventions. The U.S. Nonindigenous Aquatic Nuisance Prevention and Control Act (NANPCA) of 1990 and the National Invasive Species Act (NISA) of 1996 directed the U.S. Coast Guard to fund research on ballast water management, specifically noting that technologies in “land-based ballast water treatment facilities” could be included, and to investigate the feasibility of using or modifying onshore ballast water treatment facilities used by Alaskan oil tankers to reduce the introduction of exotic organisms (§§1101(k)(3), 1104(a)(1)(B), 1104(a)(2) and 1104(b)(3)(A)(ii) in U.S. Congress 1990, 1996). In the interim and final rules implementing NISA, the U.S. Coast Guard specifically included discharge to an onshore treatment facility as a means of meeting NISA’s ballast discharge requirements, and required ships to keep records of ballast water discharged to such facilities (US Coast Guard 1999, 2001), although the Coast Guard eliminated these provisions when it concluded that it did not have the authority to regulate or approve onshore ballast treatment plants (US Coast Guard 2004). The U.N. International Maritime Organization’s 1991 Guidelines state that “Where adequate shore reception facilities exist, discharge of ship’s ballast water in port into such facilities may provide an acceptable means of control” (IMO 1991 and IMO 1993, §7.5 Shore Reception Facilities). The IMO’s 1997 Guidelines state that “Discharge of ship's ballast water into port reception and/or treatment facilities may provide an acceptable means of control. Port State authorities wishing to utilize this strategy should ensure that the facilities are adequate...If reception facilities for ballast water and/or sediments are provided by a port State, they should, where appropriate, be utilized” (IMO 1997, §7.2.2, §9.2.3). The IMO’s 2004 Convention states that “The requirements of this regulation do not apply to ships that discharge ballast water to a reception facility designed taking into account the Guidelines developed by the Organization for such facilities” (IMO 2004, Regulation B-3.6). The IMO adopted specific guidelines for onshore ballast water treatment facilities (IMO 2006), and recognizes onshore treatment as an alternative in IMO 2005b (§1.2.3), as do Australia, New Zealand and Canada in their ballast water regulations (AQIS 1992; New Zealand 1998, 2005; Canada 2000, 2007)

B. Cost Estimate Adjustments and Calculation of Annualized and Present Value Costs

We converted estimates given in foreign currencies in the original publications into US dollars at the daily average interbank transfer rates reported at http://www.oanda.com/currency/historical-rates on the date of publication or presentation, or on the first day of the month where only the month of publication was given (Table A2-1). We adjusted estimates for inflation from the date of original publication to June 1, 2010 using the calculator at http://inflationdata.com/inflation/Inflation_Calculators/InflationCalculator.asp, which is based on the U.S. Bureau of Labor Statistics' Consumer Price Index for all Urban Consumers (CPI-U).

Table A2-1. Currency exchange rates used in this report.

Publication	Original Currency	Exchange Date	US Exchange Rate
Pollutech 1992	Canadian dollars	3/31/1992	0.845700
AQIS 1993	Australian dollars	6/1/1993	0.676000
Ogilvie 1995	New Zealand dollars	6/29/1995	0.762266
Aquatic Sciences 1996	Canadian dollars	8/1/1996	0.728000
Victoria ENRC 1997	Australian dollars	10/1/1997	0.727800

We calculated total annualized costs as the sum of the annual operations & maintenance (O&M) costs and the annualized capital costs, with annualized capital costs = $iC/(1-(1+i)^{-N})$ where i = the annual interest rate on borrowed capital, C = capital cost, and N = the working lifetime of the plant or equipment in years. This formula assumes that the entire capital cost is incurred at the start of the project period. Similarly, the present value at the start of the project period of a stream of costs occurring annually over the project period = $A(1-(1+i)^{-N})/i$ where A = the annual cost; and the present value of a single future cost F occurring at T years in the future = $F(1+i)^{-T}$.

We assumed an interest rate i = 5%, and the following working lifetimes:

New cargo vessel	25 years
Retrofitted cargo vessel	12.5 years
Treatment ship	20 years
Land-based treatment plant	30 years

C. Adjusting the Cost Estimates in Brown and Caldwell (2007) to the Design Criteria in Brown and Caldwell (2008)

The design criteria used in the two studies and the ratios between them are shown in Table A3-1. Cost estimates made on the basis of the first set of design criteria (Table A1-5 in Appendix 1A) were adjusted to reflect the second set of design criteria (Table A1-6) as described below.

Table A3-1. Design criteria in Brown and Caldwell (2007) and (2008).

Design Criterion	2007 Study	2008 Study	Ratio (2008:2007)
Ballast Discharge Rate	3,000 gpm (680 MT/h)	10,000 gpm (2,270 MT/h)	3.33
Storage	500,000 gal (1,890 MT)	2,700,000 gal (10,200 MT)	5.40
Treatment Rate	350 gpm (80 MT/h)	1,000 gpm (227 MT/h)	2.86

Capital cost of pipelines: We estimated the cost for pipelines running from berths to the treatment plant that can accommodate the 2008 study's ballast discharge rate by linear interpolation from values in Brown and Caldwell (2007), Table 4. This estimate is 1.7 times the estimate based on the 2007 study's ballast discharge rate (Brown and Caldwell 2007).

Capital cost for collection pumps (included in the column titled "Pipelines" in Tables A1-5 and A1-6): The governing criterion is the ballast discharge rate, which is 3.33 times higher in the 2008 study than in the 2007 study, so we increased the cost estimate for collection pumps by 3.33 relative to the estimate in Brown and Caldwell (2007).

Capital cost for lift station (included in the column titled "Pipelines" in Tables A1-5 and A1-6): The governing criterion is the treatment rate, which is 2.86 times higher in the 2008 study than in the 2007 study, so we increased the cost estimate for the lift station by 2.86 relative to the estimate in Brown and Caldwell (2007).

Capital cost for storage tanks: We took this figure from Table 6 in Brown and Caldwell (2007) for 3 million gallons of storage (2.7 million gallons is needed). This estimate is 2.8 times the estimate based on the 2007 study's storage requirement (Brown and Caldwell 2007).

Capital cost for barge purchase and modification: We estimated this as the cost of two barges, since 2.7 million gallons of storage is needed and one barge has a capacity of 1.7 million gallons (Brown and Caldwell 2007 at p. 15). This estimate is double the estimate based on the 2007 study's storage requirement (Brown and Caldwell 2007).

Capital costs for treatment systems: For Filtration & UV, Ozonation, and Membrane Filtration, the governing criterion is the treatment rate, which is 2.86 times higher in the 2008 study than in the 2007 study, so we increased the cost estimates by 2.86 relative to the estimates in Brown and Caldwell (2007).

For Hydrodynamic Cavitation, part of the capital cost is for additional storage. We took this part of the cost from Table 6 in Brown and Caldwell (2007) for 3 million gallons of storage (2.7 million gallons is needed). For the remaining part of the capital cost, the governing criterion is the treatment rate which is 2.86 times higher in the 2008 study than in the 2007 study, so we increased the estimate by 2.86 relative to the estimate in Brown and Caldwell (2007).

Barge O&M: These costs are for towing services, based on the number of ship arrivals per year, which did not change between the two studies. We made no change in this estimate.

Treatment system O&M: These costs, and equipment replacement costs included under O&M, appear to be based on the total annual volume of ballast water discharged, which did not change between the two studies. We made no change in this estimate.

We captured economies of scale in the modified estimates for pipelines, storage tanks and barges by basing them on tables of costs in Brown and Caldwell (2007); thus the ratios of estimated costs are less than the ratios of the governing design criteria (Table A3-2). For the other cost estimates, no economies of scale were captured; by this factor, the modified cost estimates in Table A1-6 are probably somewhat high.

Table A3-2. Comparison of criteria and cost estimate ratios for pipe, storage and barge estimates.

Estimated Cost	Governing Criteria	Ratio of Design Criteria	Ratio of Cost Estimates
Pipelines	Ballast Discharge Rate	3.33	1.7
Storage Tanks	Storage	5.40	2.8
Barges	Storage	5.40	2.0

D. Estimating the Number of Treatment Plants and Treatment Capacities needed for Onshore vs. Shipboard Treatment Approaches for Milwaukee, Australia, California and the United States

This appendix explains the calculation of the estimates summarized in Table VI.B-2.

Shipboard ballast water treatment systems must generally be sized large enough to accommodate the maximum ballast pumping capacities of the ships they are installed on (Table A4-1). This requires some very large-capacity treatment plants, comparable to the size of wastewater treatment plants for some large urban areas (Table A4-2): the 20,000 MT/h capacity needed for the largest vessels is greater than the estimated wastewater treatment capacity needed to serve the population of Phoenix, Arizona, the fifth largest city in the United States. In contrast, onshore ballast treatment plants with adequate storage need only be large enough to treat at the average (not the maximum) ballast discharge rate.

Table A4-1. Ships' total ballast pump capacities. The total ballast pump capacity is the summed capacities of all ballast pumps that can operate simultaneously on the ship.

Vessel Type	Typical Total Ballast Pump Capacity (MT/h)	Reference
Containerships	250-750	ABS 2010
Australian Containerships	500-2,000	AQIS 1993a
Containerships	1,100	Rigby & Taylor 2001b
Containerships	1,000-2,000	NRC 1996
Japan-Oregon Woodchip Carriers	780-975	Carlton et al. 1995
Australian Woodchip Carriers	1,000-1,500	AQIS 1993a
Bulk Carriers	1,300-3,000	ABS 2010
Australian Bulk Carriers	1,000-6,000	AQIS 1993a
Capesize Bulk Carriers	6,000	Rigby & Taylor 2001b
Bulk Carriers	2,000-10,000	Reeves 1999
Bulk Carriers, Ore Carriers	5,000-10,000	NRC 1996
Largest Bulk Carriers	to >20,000	AQIS 199a
Australian Tankers	750-3,000	AQIS 1993a
Tankers	1,100-5,800	ABS 2010
LNG Tanker	6,000	Rigby & Taylor 2001b
Tankers	5,000-20,000	NRC 1996; Reeves 1999
Largest Tankers	to >20,000	AQIS 199a
New Zealand ships	1,000-1,500	Ogilvie 1999
Great Lakes ships	550-3,500	Brown and Caldwell 2008
Great Lakes ships	400-5,000	Pollutech 1992
Great Lakes ships	2,000-5,900	Aquatic Sciences 1996
Largest vessels	15,000-20,000	NRC 1996

Table A4-2. Estimated wastewater treatment capacities needed to serve the populations of selected US cities. Based on July 1, 2008 populations (U.S. Census 2010) and the average per capita domestic wastewater production in North America (UNEP 2000). Rank is the rank among U.S. cities in population (U.S. Census 2010).

Treatment Capacity (MT/h)	City	Population	Rank
16,987	Phoenix AZ	1,568,000	5
4,474	Miami FL	413,000	43
1,972	Salt Lake City UT	182,000	125
1,343	Hartford CT	124,000	193

The treatment plants and treatment capacities needed for onshore treatment in the Port of Milwaukee, Australia and California were estimated based on conceptual design studies of onshore treatment in those locations (with various adjustments described below). The estimate for the U.S. was based on the California estimate adjusted to reflect the larger amount of ballast water that is discharged in the U.S. The shipboard treatment estimates were based on the estimated number of ships arriving or discharging ballast in these locations (for the number of treatment plants), multiplied by the average ballast pump capacity of these ships (for the treatment capacity). For sites with onshore studies that include land-based treatment plants, the project period is the estimated useful life of 30 years for a land-based treatment plant (Appendix 1B). For the onshore study based on a treatment ship only (Brown and Caldwell 2008), the project period is 20 years. For each site, the estimated number of affected ships for the shipboard estimate was based on these project periods, adjusted to reflect the estimated 25-year useful life of a ship.

In each of these estimates, adjustments were selected that are *conservative* in the sense of tending to produce a smaller shipboard:onshore ratio for treatment plants or treatment capacity, which is the sense in which the word is used below. That is, as used in this appendix, conservative adjustments are those that tend to raise the number of treatment plants or the total treatment capacity needed for onshore treatment, or to lower those numbers for shipboard treatment.

Port of Milwaukee (overseas ships only)

Onshore estimate: Brown and Caldwell (2008) estimated that a single ballast water treatment ship with a maximum treatment rate of 230 MT/h could serve the overseas ships calling at the Port of Milwaukee.

Shipboard estimate, number of treatment plants: About 85 overseas ships call at the port each year during the 8 months that the St. Lawrence Seaway is open (Brown and Caldwell 2008). Assuming that each roundtrip voyage takes a month, this would require a minimum of 11 different overseas cargo ships to visit the port during the first year. Over the remaining 19 years of the 20-year period of the estimate (corresponding to the estimated useful working life a treatment ship), other overseas cargo ships would call at the Port consisting of a combination of (a) new ships that come into service to replace ships that had called at the Port during the first year, and (b) other ships, including other new ships and old ships that hadn't called at the Port during the first year. With a typical useful working life for a cargo ship of 25 years, approximately 19/25 of the ships calling at the Port in the first year will go out of service and be replaced by other vessels during the remainder of the 20-year period. Since raising the number of ships raises the number of treatment plants and the total treatment capacity that would need to be installed to accommodate shipboard treatment, we conservatively adjust the number of ships by counting only the additional ships that call as replacements for the ships that called during the first year (a), and ignoring other ships (b). The estimated number of distinct ships, and of treatment plants needed, is thus 19 (= 11 x (1 + 19/25)).

Shipboard estimate, treatment capacity: In describing ships at the Port of Milwaukee, Brown and Caldwell (2008) state that "typically, cargo ships have two to three pumps that pump the ballast water to one of the various discharge locations on the ship...In general, each of the pumps within the ballast water tanks has a capacity that ranges from 1,000 gpm to 5,000 gpm, and often two of the pumps operate simultaneously." Thus, these ships typically have ballast pump capacities of 2,000 gpm (≈450 MT/h) to 10,000-15,000 gpm (≈2,300-3,400 MT/h). For the estimate, we assumed an average capacity of 1,200 MT/h (equivalent to two 2,650 gpm pumps). With 19 distinct ships, the total treatment capacity that will need to be installed is 22,800 MT/h.

<u>Australia</u>

Onshore estimate: AQIS (1993a) estimated that Australia's domestic and foreign ballast discharges could be treated with 3 treatment ships and 18 land-based treatment plants located in Australia's major ports, along with 16 barges to transport ballast water collected at smaller ports. Since the estimated working lives are 20 years for a treatment ship and 30 years for a land-based plant, a 30-year period was used for the estimate and the number of treatment ships required was increased to 5. This is a conservative adjustment, since the calculated need over 30 years is for only 4.5 treatment ships. The total treatment capacity of the 18 land-based plants and 5 treatment ships is 34,900 MT/h.

Shipboard estimate: AQIS (1993a, pp. 86, 88) reported that at least 1,000 different ships visit Australian ports each year, discharging 66 million MT of ballast water. If each of these ships discharges its entire typical ballast load into Australian waters once a month, the typical ballast load would be 5,500 MT. Data on Australian ships shows that ballast pump capacities are about 10% of typical ballast loads (AQIS 1993a, Table 4.1), thus the average ballast pump capacity for Australian vessels is estimated to be 550 MT/h. This is almost certainly a substantially conservative estimate, since AQIS (1993a, Table 4.1) lists typical ballast pump capacities for ships in Australia ranging from 500 MT/h (for small containerships) to 6,000 MT/h (for large bulk carriers), with an unweighted average for different ship types of 2,090 MT/h. Using a higher estimate of average ballast pump capacity would produce a correspondingly higher estimate of the total treatment capacity needed.

Adjusting the ship numbers to a 30-year period by adding only the expected number of replacement ships (and ignoring other ships, a conservative adjustment) yields 2,160 distinct ships requiring 2,160 treatment plants. With an average ballast pump capacity of 550 MT/h, a total treatment capacity of 1.2 million MT/h would need to be installed over the project period.

California

Onshore estimate: CAPA (2000) estimated that 10 onshore treatment plants (one at each of ten ports) with a total treatment capacity of 489 MT/h could treat the ballast water discharged into California waters. However, the port descriptions in this study suggested that it would be more economically efficient to serve some of the ports with a few smaller treatment plants rather than a single larger one, so we instead estimated that a total of 16 onshore plants are needed.

The conceptual design in CAPA (2000) provided sufficient storage at each site to allow the plants to treat ballast water at the average rate of discharge. However, the study developed designs and cost estimates for only a few sizes of treatment plant, and allocated to each port the next plant size greater than the average ballast discharge at that port. In some cases these plants were nearly 50% larger than needed, resulting in an estimate of total treatment capacity needed in the state (489 MT/h) that is nearly 30% higher than the average rate of discharge in the state (377 MT/h). We conservatively based our estimate on the higher estimate used in the CAPA (2000) report.

The estimates in CAPA (2000) were based on some of the earliest ballast discharge data collected by the U.S. Coast Guard and the State of California, which covered less than a year at the time of the study, only included data from ships that had traveled overseas, and suffered from low reporting rates. CAPA (2000) corrected for the time period (that is, annualized the data) but not for the other data limitations. We utilized the most recent available report from the National Ballast Information Clearinghouse summarizing U.S. Coast Guard ballast water data (Miller et al. 2007, covering data for 2004-2005), adjusted these data for reporting rates aggregated by Captain of the Port Zones (COPTZ) in California, and summed these for both foreign and domestic ballast water to estimate total ballast discharge in California (Table A4-3). We then adjusted the treatment capacity estimate from CAPA (2000) by the ratio between the estimate that we derived for California discharge from the Miller et al. (2007) data (12,250,000 MT/y) and the CAPA (2000) estimate for California discharge (3,303,000 MT/y, summed from Table 5.2 in CAPA (2000)), yielding an estimate of 1,814 MT/h of onshore treatment capacity needed in California (or nearly 4 times the estimate in CAPA (2000)).

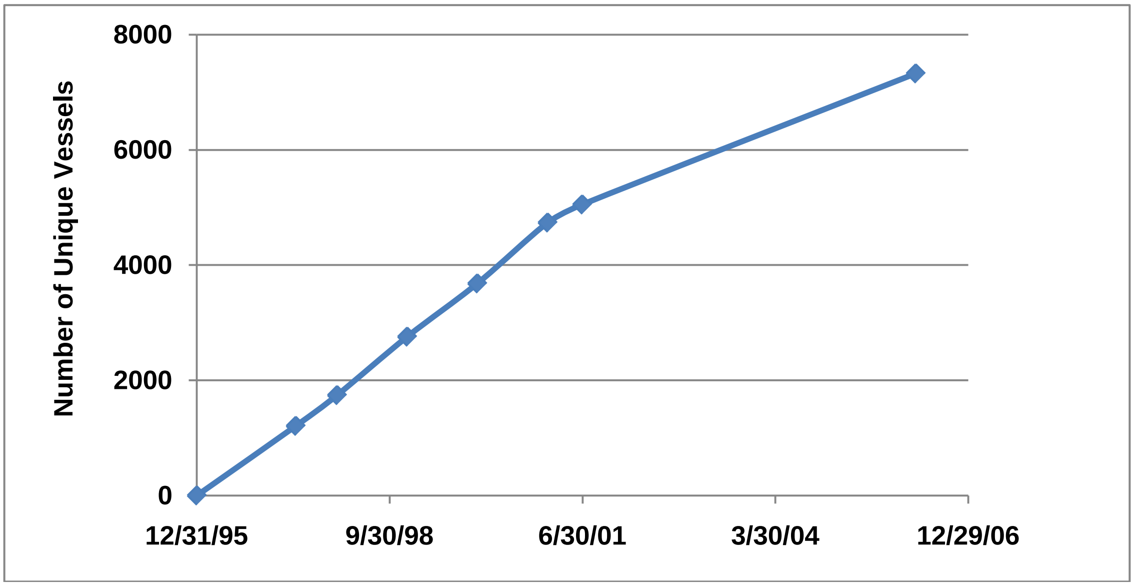
Table A4-3. Estimate of the total annual ballast water discharge into California waters (metric tons).

	Domestic			**Foreign**			**Total**
	Reported Discharge	Reporting Rate	Estimated Discharge	Reported Discharge	Reporting Rate	Estimated Discharge	Estimated Discharge
Source:	Table 8	Table 4		Table 6	Table 3		
DATA FOR 2004-2005							
SFCMS	4,379,050	104.8	4,178,000	2,975,652	73.7	4,038,000	8,216,000
LOSMS	4,612,242	78.6	5,868,000	5,741,283	98.4	5,835,000	11,703,000
SDCMS	3,452,378	77.7	4,443,000	112,825	80.4	140,000	4,583,000
California			14,489,000			10,013,000	24,502,000
ANNUAL DATA							
California			7,244,500			5,006,500	12,251,000

Source is the table in Miller et al. 2007 from which the data were taken. Captain of the Port Zones are: SFCMS = San Francisco; LOSMS = Los Angeles-Long Beach; SDCMS = San Diego

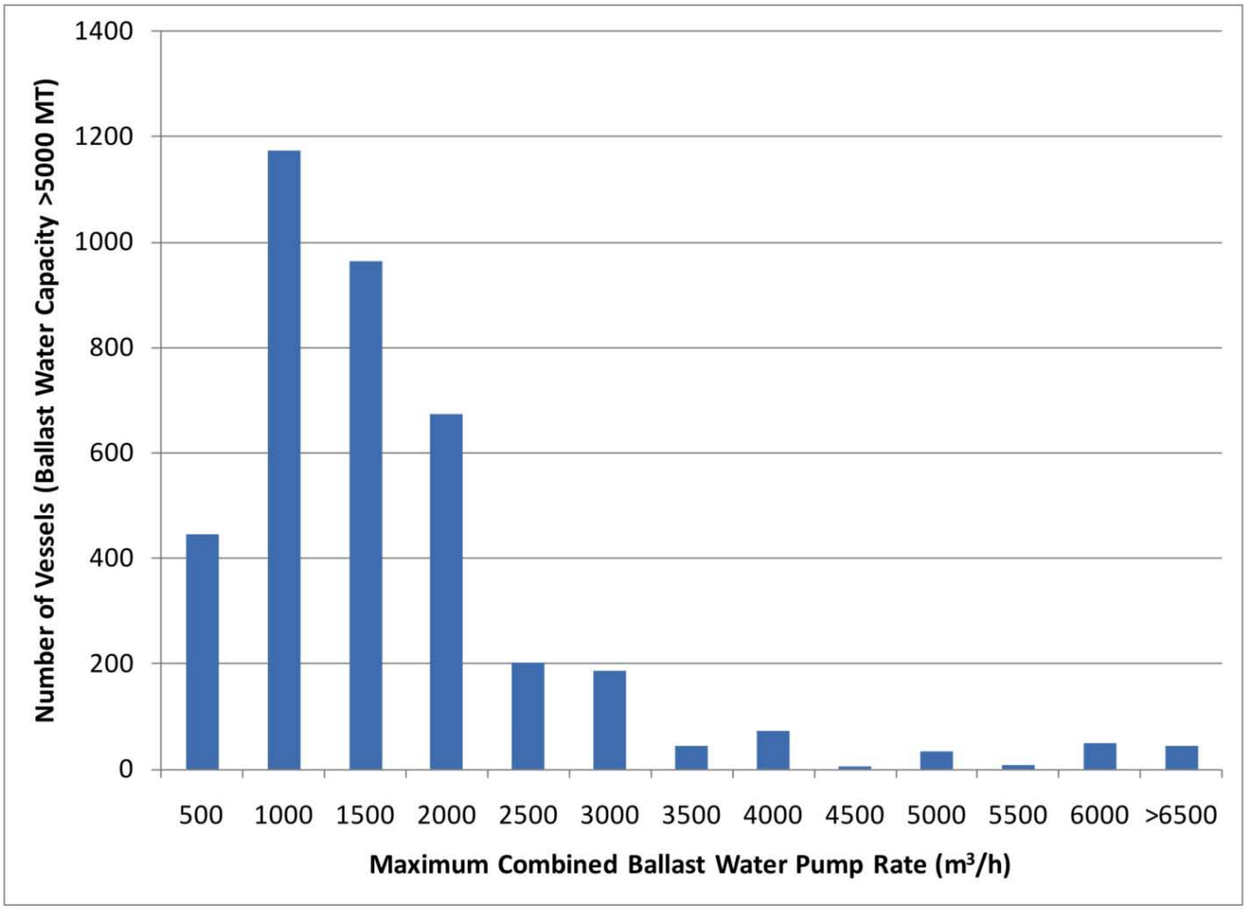
Shipboard estimate, number of treatment plants: Figure A4-1 below shows the estimated cumulative number of distinct ships arriving at California ports since January 1, 2000, based on data provided by the California State Lands Commission or contained in California SLC (2010). It's not clear whether the data for the first 4.5 years includes ships on coastal voyages, since such ships were not required to file ballast water report forms during that time; if these are not included, Figure A4-1 could substantially underestimate the number of distinct ships. A total of 7,327 distinct ships were recorded through March 31, 2010, a period of 10.25 years. Adjusting the ship numbers for the 30-year period by adding only the expected number of replacement ships (a conservative adjustment) yields 13,115 distinct ships expected to be subject to ballast water regulations, potentially requiring 13,115 treatment plants. However, not all arriving ships discharge ballast water, so it's not clear whether all of these ships would need a treatment plant installed. This is discussed further below under the estimate of shipboard treatment capacity.

Figure A4-1. Cumulative number of unique ships arriving at California ports since January 1, 2000. Includes a small number of unmanned barges (a total of 28 through June 2005).



Shipboard estimate, treatment capacity: Figure A4-2 shows California State Lands Commission data on the ballast pump capacities in a sample of nearly 4,000 distinct ships arriving in California ports. The average ballast pump capacity estimated from this figure is 1,436 MT/h. With 13,115 distinct ships, this yields an estimate of nearly 19 million MT/h of treatment capacity that would need to be installed.

Figure A4-2. Total ballast pump capacities of ships that call at California ports. Source: California SLC 2010, Fig. VI-3.



As mentioned, not all vessels discharge ballast water on arriving at a California port, so not all of the distinct arriving ships may need to install treatment plants. Thus the estimates presented in this appendix could overestimate the number of plants and the treatment capacity needed for shipboard treatment. How significant could this overestimation be? On average, only 20% of ship arrivals at California ports report discharging ballast water (California SLC 2010); however, there is no independent verification of whether ships have or have not discharged ballast water, and there are reasons to suspect that ships often fail to report some of their discharges. Glosten (2002) reported that they "were often told by agents and operators that their vessels never discharge ballast in Puget Sound. However, we found that almost every vessel surveyed discharged ballast at some point while they were in port, usually for trim and list control, while loading and off-loading cargo." Glosten (2002) concluded that the under-reporting occurred because many ship operators mistakenly excluded practices involving the discharge of relatively small volumes of ballast water from their definition of ballast discharge. However, there is also a financial incentive for ship operators to not report ballast discharges: a ship reporting that it intends to discharge ballast is more likely to have its ballast tanks sampled, which is an inconvenience that involves some risk of delay and increases the chance that it will be found to be out of compliance and subjected to penalties. Studies in Australia (Lockwood

1999), the Great Lakes (Reeves 1998) and Washington (Harkless 2003; Lyles 2004) found evidence that ships routinely misreported their ballast management activities (see also Cohen & Foster 2000 at footnote 163). Harkless (2003) reported that some Chief Mates admitted that they intentionally reported false ballast water information in order to satisfy regulators.

Even if the figure of ballast discharge by only 20% of California ship arrivals is accurate, more than 20% of the individual ships might discharge ballast on *some* voyages. For example, if every arriving ship discharged ballast on half of its arrivals, then 100% of ships would need to treat ballast water even though only 50% of arrivals involved ballast discharges. As a sensitivity test, we recalculated the treatment plant and capacity estimates for California assuming that only 20% of arriving ships ever discharge ballast water in the state (Table A4-4; compare to Table VI.B-2). In this case the number of treatment plants needed for shipboard treatment is 164 times the number needed for onshore treatment (down from 820 in Table VI.B-2) and the treatment capacity needed is 2,076 times the need with onshore treatment (down from 10,382 in Table VI.B-2). Though less, the difference is still striking.

Table A4-4. Treatment plant and capacity estimates for California, assuming that only 20% of ships arriving in California ever discharge ballast water there.

	Number of Treatment Plants		Total Capacity of Treatment Plants (MT/h)	
Site	**Onshore**	**Shipboard**	**Onshore**	**Shipboard**
California	16	2,623	1,814	3,767,000

<u>United States</u>

Onshore estimate: To estimate the number of onshore treatment plants and the treatment capacity needed in the United States, we started with the estimates for California derived above. We then multiplied these by the ratio between the estimated total ballast water discharge in the United States (239,990,000 MT/y derived from Miller et al. 2007, Table A4-5) and the estimated discharge in California (12,251,000 MT/y). This yielded an estimate of 314 onshore treatment plants needed with a total treatment capacity of 35,550 MT/h.

Table A4-5. Estimate of the total annual ballast water discharge into U.S. waters, compared to the estimate for California.

	Reported Discharge	Domestic Reporting Rate	Estimated Discharge	Reported Discharge	Foreign Reporting Rate	Estimated Discharge	Total Estimated Discharge
US 2004-05	183,792,889	48.9	375,855,000	73,720,328	70.8	104,125,000	479,980,000
US annual	–	–	187,927,500	–	–	52,062,500	239,990,000
CA annual	–	–	7,244,500	–	–	5,006,500	12,251,000

Shipboard estimate: Approximately 40,000 cargo ships (excluding barges) are estimated to be subject to ballast water discharge requirements in the United States over the five-year VGP period (Albert & Everett 2010; Ryan Albert, pers. comm., SAB teleconference 10/26/2010). Adjusting the ship numbers for a 30-year period by adding only the expected number of replacement ships (a conservative adjustment) and assuming an average 25-year lifetime for a ship yields 80,000 distinct ships requiring 80,000 treatment plants that would need to be installed over the project period. No data on ballast pump capacities comparable to the California data in Figure 2 are available for the U.S. as whole. We used California's average ballast pump capacity of 1,436 MT/h, to yield an estimate of total treatment capacity of 115 million MT/h need for shipboard treatment.

E. Cost Comparison

This appendix shows the source data and explains the calculations of the cost comparison in §VI.E "Cost of Onshore vs. Shipboard Treatment". The calculations are for cost estimates as of June 1, 2010; assumptions and some input data from Appendix 1D are listed in Table A5-1. The inflation rates are based on the U.S. Bureau of Labor Statistics' Consumer Price Index for all Urban Consumers (CPI-U). Annualized costs are calculated as described in Appendix 1B. In these calculations, all significant digits in the original data were carried through each stage of the calculation, but were rounded off before they were entered in the tables. Thus, the column and row totals may not precisely match the totals entered in the tables due to rounding.

Table A5-1. Assumptions and some input data for the cost comparison.

0.05	Annual interest rate
30 y	Lifetime of onshore components
25 y	Lifetime of new ship outfitted at the time of construction with treatment plants or with pipes and pumps to discharge ballast water onshore; shipboard treatment plant, pipes and pumps assumed to have the same lifetime as the ship
12.5 y	Remaining lifetime of old ships retrofitted with treatment plants or with pipes and pumps to discharge ballast water onshore; shipboard treatment plant, pipes and pumps assumed to have the same lifetime as the ship
1.2548	Inflation from 9/1/2000 to 6/1/2010 (from publication of CAPA 2000 to June 1, 2010)
1.2307	Inflation from 1/1/2002 to 6/1/2010 (from publication of Glosten 2002 to June 1, 2010
0.9949	Inflation from 8/1/2008 to 6/1/2010 (from publication of Brown and Caldwell 2008 to June 1, 2010)
1.0056	Inflation from 2/1/2010 to 6/1/2010 (from publication of Lloyd's Register 2010 to June 1, 2010)
3,303,000 MT/y	Total California ballast water discharge, as reported in CAPA 2000
12,251,000 MT/y	Total California ballast water discharge based on the most recent NBIC report, Miller et al. 2007 (covering 2004-05), foreign & domestic combined, adjusted for reporting rates
239,990,000 MT/y	Total U.S. ballast water discharge based on the most recent NBIC report, Miller et al. 2007 (covering 2004-05), foreign & domestic combined, adjusted for reporting rates
3.7	Ratio of the California ballast water discharge estimate based on Miller et al. 2007 to the estimate in CAPA 2000
19.6	Ratio of the U.S. to the California ballast water discharge estimates based on Miller et al. 2007
13,115	Estimated number of ships in California that will need to treat ballast water over the 30-year project period.
80,000	Estimated number of cargo ships in the U.S. that will need to treat ballast water over the 30-year project period.

Onshore Cost - On-land Component - California

The estimates described here are summarized in Table VI.E-1. The original cost data from CAPA (2000) is shown in Table A5-2, except that under Annualized Costs, the first column shows the figures from CAPA (2000) and the second column shows the annualized costs we calculated by the method described in Appendix 1B.

Table A5-2. **Costs for onshore treatment in California from CAPA (2000).**

Port	Capital Costs				Annual O&M	Annualized Costs	
	Pipelines	Storage Tanks	Treatment Plants	Outfalls		CAPA	Calculated
Hueneme	1,056,000	55,000	0	100,000	0	40,367	78,780
Humboldt Bay	12,672,000	4,000,000	1,781,000	100,000	149,800	768,233	1,357,000
Long Beach	28,617,600	5,100,000	2,220,400	100,000	223,454	1,424,721	2,568,000
Los Angeles	27,033,600	20,400,000	2,220,400	100,000	223,454	1,881,921	3,460,000
Oakland	15,840,000	3,800,000	1,781,000	100,000	149,800	867,167	1,550,000
Redwood City	1,584,000	4,300,000	1,631,500	100,000	142,400	396,250	638,000
Richmond	5,808,000	3,400,000	1,631,500	100,000	142,400	507,050	854,000
Sacramento	1,372,800	4,800,000	1,631,500	100,000	142,400	405,877	656,600
San Diego	9,292,800	3,100,000	1,631,500	100,000	142,400	613,210	1,061,000
San Francisco	8,448,000	6,300,000	1,781,000	100,000	149,800	704,100	1,232,000
Stockton	5,385,600	5,500,000	1,631,500	100,000	142,400	562,970	963,200
Calif. Total	117,110,400	60,755,000	17,941,300	1,100,000	1,608,308	8,171,865	14,420,000

Table A5-3 shows the costs from Table A5-2, not including the CAPA (2000) figures for annualized costs, adjusted for inflation.

Table A5-3. **Costs for onshore treatment in California from CAPA (2000), adjusted for inflation.**

Port	Capital Costs				Annual O&M	Annualized Costs
	Pipelines	Storage Tanks	Treatment Plants	Outfalls		
Hueneme	1,325,000	69,000	0	125,500	0	98,850
Humboldt Bay	15,900,000	5,019,000	2,235,000	125,500	188,000	1,702,000
Long Beach	35,910,000	6,399,00	2,786,000	125,500	280,400	3,222,000
Los Angeles	33,920.000	25,600,000	2,786,000	125,500	280,400	4,342,000
Oakland	19,880,000	4,768,000	2,235,000	125,500	188,000	1,945,000
Redwood City	1,988,000	5,396,000	2,047,000	125,500	178,700	800,300
Richmond	7,288,000	4,266,000	2,047,000	125,500	178,700	1,072,000

Port	Capital Costs				Annual	Annualized
Sacramento	1,723,000	6,023,000	2,047,000	125,500	178,700	823,900
San Diego	11,660,000	3,890,000	2,047,000	125,500	178,700	1,332,000
San Francisco	10,600,000	7,905,000	2,235,000	125,500	188,000	1,545,000
Stockton	6,758,000	6,901,4000	2,047,000	125,500	178,700	1,209,000
Calif. Total	146,950,000	76,235,000	22,510,000	1,380,000	2,018,000	18,090,000

Table A5-4 shows the costs from Table A5-3 adjusted to correspond to a 3.7 times higher estimate of ballast water discharge than was used in CAPA (2000). These adjustments include the following:

• *Pipeline Capital Costs*: Costs from Table A5-3 were adjusted by (1) multiplying the maximum discharge/day for each port (from CAPA 2000, Table 4.4) by 3.7; (2) selecting the least-cost set of pipe sizes from Brown and Caldwell (2007, Table 4) that are capable of handling the adjusted maximum discharge/day, expressed as gallons per minute (gpm); (3) multiplying the construction cost per lineal foot (Brown and Caldwell 2007, Table 4) times the total length of pipe needed at that port (CAPA 2000, Table 4.2); (4) adding 25% for contingency and 30% for technical services (per Brown and Caldwell 2007); and (5) inflating to June 1, 2010 dollars. The details of the pipeline calculations are shown below in Table A5-5. This approach tends to overestimate costs in that it overestimates the pipe sizes needed (total pipe capacity exceeds the adjusted maximum discharge by 27% in Table A5-5).

• *Storage Tank and Outfall Capital Costs, and Annual O&M*: Costs from Table A5-3 were multiplied by 3.7. This approach tends to overestimate the costs (especially capital costs) in that it fails to capture economies of scale for the larger tank and outfall sizes.

• *Treatment Plant Capital Costs*: Costs from Table A5-3 were adjusted by (1) multiplying the required treatment capacity for each port (CAPA 2000, Table 4.5) by 3.7; (2) selecting the least-cost set of treatment plant sizes from CAPA (2000, Table 4.7) that can provide the adjusted treatment capacity; and (3) inflating to June 1, 2010 dollars. This estimate includes 30% for contingency per CAPA (2000). The details of the treatment plant calculations are shown below in Table A5-6. This approach tends to overestimate costs in that it overestimates the treatment plant sizes needed (total treatment plant size exceeds the adjusted required treatment capacity by 51% in Table A5-6) and fails to capture economies of scale in the larger plants.

Table A5-4. Costs for onshore treatment in California from CAPA (2000), adjusted to an updated estimate for California ballast water discharge and adjusted for inflation.

Port	Capital Costs				Annual O&M	Annualized Costs
	Pipelines	Storage Tanks	Treatment Plants	Outfalls		
Hueneme	1,246,000	256,000	0	465,400	0	128,000
Humboldt Bay	34,350,000	18,620,000	2,786,000	465,400	697,200	4,354,000

Port	Capital Costs				Annual O&M	Annualized Costs
	Pipelines	Storage Tanks	Treatment Plants	Outfalls		
Long Beach	77,600,000	23,740,000	8,358,000	465,400	1,040,000	8,206,000
Los Angeles	238,300,000	94,950,000	11,140,000	465,400	1,040,000	23,475,000
Oakland	42,900,000	17,690,000	2,786,000	465,400	697,200	4,850,000
Redwood City	3,738,000	20,010,000	2,786,000	465,400	662,800	2,419,000
Richmond	15,840,000	15,820,000	2,235,00	465,400	662,800	2,898,000
Sacramento	3,738,000	22,340,000	2,786,000	465,400	662,800	2,571,000
San Diego	20,530.000	14,430,000	2,786,000	465,400	662,800	3,149,000
San Francisco	22,960,000	29,320,000	2,786000	465,400	697,200	4,310,000
Stockton	14,590,000	25,600,000	2,235,00	465,400	662,800	3,453,000
Calif. Total	475,800,000	282,800,000	40,690,000	5,120,000	7,485,000	59,810,000

Table A5-5. Estimate of Pipeline Capital Costs for onshore treatment in California. CAPA Maximum Discharge is from CAPA (2000), Table 4.4. Adjusted Maximum Discharge is CAPA Maximum Discharge multiplied by 3.7 and expressed as gpm. Pipe Capacity and Pipe Diameter are the sizes listed in Brown and Caldwell (2007), Table 4 needed to accommodate the Adjusted Maximum Discharge (3 pipes (in the listed sizes) are need for the Port of Los Angeles); Unit Construction Cost is from the same table. Pipeline Length is from CAPA (2000), Table 5.1. Total Capital Cost is Unit Construction Cost times Pipe Length, adjusted for inflation.

Port	CAPA Maximum Discharge (gpd)	Adjusted Maximum Discharge (gpm)	Pipe Capacity (gpm)	Pipe Diameter (in)	Unit Construction Cost (lineal foot)	Pipeline Length (km)	Total Capital Cost
Hueneme	54,128	140	1,000	10	140	1.6	1,246,000
Humboldt Bay	3,944,058	10,200	16,667	36	320	19.3	34,350,000
Long Beach	5,104,821	13,100	16,667	36	320	43.6	77,600,000
Los Angeles #1			25,000	42	440		
Los Angeles #2	20,285,271	52,300	25,000	42	440	41.2	238,300,000
Los Angeles #3			3,000	16	160		
Oakland	3,667,472	9,400	16,667	36	320	24	42,900,000
Redwood City	4,181,547	10,800	16,667	36	320	2	3,738,000
Richmond	3,312,692	8,500	16,667	36	320	9	15,840,000
Sacramento	4,711,895	12,100	16,667	36	320	2	3,738,000
San Diego	3,016,584	7,800	8,333	30	260	14	20,530.000
San Francisco	6,202,051	16,000	16,667	36	320	13	22,960,000
Stockton	5,469,666	14,000	16,667	36	320	8	14,590,000
Calif. Total	59,950,185	154,000	195,669	–	–	178	475,800,000

Table A5-6. Estimate of Treatment Plant Capital Costs for onshore treatment in California. CAPA Required Treatment Capacity is from CAPA (2000), Table 4.5. Adjusted Required Treatment Capacity is CAPA Required Treatment Capacity multiplied by 3.7. Treatment Plant Size is the minimum plant size as a multiple of the plant sizes (0.1, 0.2 and 1.0 mgd) with cost estimates in CAPA (2000), and Plant Cost is estimated as multiples of the CAPA (2000) cost estimates (i.e. the cost of a 3 mgd plant is estimated as 3 times CAPA's cost estimate for a 1 mgd plant), adjusted for inflation.

Port	CAPA Required Treatment Capacity (gpd)	Adjusted Required Treatment Capacity (gpd)	Treatment Plant Size (mgd)	Plant Cost
Hueneme	497	1,800	–	–
Humboldt Bay	140,084	520,000	1	2,786,000
Long Beach	679,714	2,500,000	3	8,358,000
Los Angeles	993,539	3,700,000	4	11,140,000
Oakland	159,694	590,000	1	2,786,000
Redwood City	56,493	210,000	1	2,786,000
Richmond	44,269	165,000	0.2	2,235,000
Sacramento	99,306	370,000	1	2,786,000
San Diego	56,986	210,000	1	2,786,000
San Francisco	109,124	405,000	1	2,786000
Stockton	50,843	190,000	0.2	2,235,00
California Total	2,390,549	8,870,000	13.4	40,690,000

The area needed for storage tanks was estimated as described in Table A5-7, and the area needed for treatment plants was estimated as 0.25 acres for a 0.2 mgd plant, and 1 acre/mgd for plants ≥1 mgd. Land Costs were estimated as shown in Table A5-8, with supporting data shown in Table A5-9. Land costs were added to the Storage and Treatment Plant capital costs in Table A5-4 to produce Table A5-10.

Table A5-7. Estimate of land needed for storage tanks for onshore treatment in California. CAPA Storage Needed is from CAPA (2000), Table 4.5. Adjusted Storage Needed is CAPA Storage Needed multiplied by 3.7. Number of Tanks is the minimum number of steel tanks of 7.3 m height and 60 m maximum diameter needed to provide the Adjusted Storage Needed. Tank Diameter gives the corresponding tank diameters. Tank Area is the area needed if each tank occupies a square with a 1 m buffer (i.e. a square whose sides equal the tank diameter plus 2 m).

Port	CAPA Storage Needed (gal)	Adjusted Storage Needed (gal)	Number of Tanks	Tank Diameter (m)	Tank Area (acres)
Hueneme	108,257	401,500	1	16.3	0.08
Humboldt Bay	7,888,116	29,260,000	6	56.7	5.1
Long Beach	10,209,642	37,870,000	7	59.8	6.6
Los Angeles	40,570,700	150,500,000	28	59.6	26.2
Oakland	7,334,944	27,210,000	5	59.9	4.7
Redwood City	8,363,094	31,020,000	6	58.4	5.4

Port	CAPA Storage Needed (gal)	Adjusted Storage Needed (gal)	Number of Tanks	Tank Diameter (m)	Tank Area (acres)
Richmond	6,625,384	24,570,000	5	57.0	4.3
Sacramento	9,423,472	34,950,000	7	57.4	6.1
San Diego	6,033,114	22,380,000	5	54.4	3.9
San Francisco	12,403,838	46,010,000	9	58.1	8.0
Stockton	10,939,280	40,570,000	8	57.9	7.1
California Total	119,899,842	444,700,000	87	–	77.6

Table A5-8. Estimate of land costs for onshore treatment in California. Storage tank and treatment plant areas estimated as described in the text and Table A5-7. Per acre land costs estimated from the records in Table A5-9.

Port	Storage Tank Area (acres)	Treatment Plant Area (acres)	Land Cost per acre	Land Cost - Storage	Land Cost- Treatment
Hueneme	0.08	–	500,000	41,000	0
Humboldt Bay	5.1	1	700,000	3,580,000	700,000
Long Beach	6.6	3	1,000,000	6,600,000	3,000,000
Los Angeles	26.2	4	2,000,000	52,500,000	8,000,000
Oakland	4.7	1	700,000	3,300,000	700,000
Redwood City	5.4	1	500,000	2,700,000	500,000
Richmond	4.3	.25	500,000	2,150,000	125,000
Sacramento	6.1	1	500,000	3,000,000	500,000
San Diego	3.9	1	1,000,000	3,900,000	1,000,000
San Francisco	8.0	1	2,000,000	16,000,000	2,000,000
Stockton	7.1	.25	100,000	700,000	25,000
California Total	77.6	13.5	–	94,600,000	16,550,000

Table A5-9. Price of vacant industrial or commercial land offered for sale near ports. From http://www.cityfeet.com, accessed 12/1/10.

Port	Acres in parcel	Asking price per acre	Port	Acres in parcel	Asking price per acre
Humboldt Bay	3	633,333	Oakland	1	795,000
Humboldt Bay	2	604,167	Oakland	2.9	1,818,182
Long Beach	5.6	1,094,643	Redwood City	1	1,475,000
Long Beach	12.4	958,237	Redwood City	0.4	547,945
Los Angeles	1.0	932,697	Richmond	1	398,000
Los Angeles	1.0	1,350,000	Sacramento	4	381,150
Los Angeles	2.0	3,750,000	San Francisco	1.5	1,503,881
Oakland	19	684,211	Stockton	3	77,746

Table A5-10. Costs for onshore treatment in California from CAPA (2000), adjusted to an updated estimate for California ballast water discharge and for inflation, including land costs.

Port	Capital Costs				Annual O&M	Annualized Costs
	Pipelines	Storage Tanks	Treatment Plants	Outfalls		
Hueneme	1,246,000	297,000	0	465,400	0	130,700
Humboldt Bay	34,350,000	22,200,000	3,486,000	465,400	697,200	4,633,000
Long Beach	77,600,000	30,330,000	11,360,000	465,400	1,040,000	8,830,000
Los Angeles	238,300,000	147,400,000	19,140,000	465,400	1,040,000	27,400,000
Oakland	42,900,000	21,000,000	3,486,000	465,400	697,200	5,111,000
Redwood City	3,738,000	22,720,000	3,286,000	465,400	662,800	2,628,000
Richmond	15,840,000	17,970,000	2,359,799	465,400	662,800	3,046,000
Sacramento	3,738,000	25,390,000	3,286,000	465,400	662,800	2,802,000
San Diego	20,530.000	18,350,000	3,786,000	465,400	662,800	3,469,000
San Francisco	22,960,000	45,380,000	4,786,000	465,400	697,200	5,485,000
Stockton	14,590,000	26,310,000	2,260,000	465,400	662,800	3,501,000
Calif. Total	475,800,000	377,400,000	57,240,000	5,120,000	7,485,000	67,040,000

Onshore Cost - On-land Component - United States

As described in §VI.E.2, we estimated the on-land components of onshore costs (pipelines including screening/lift stations; storage tanks; treatment plants; and outfalls) for the U.S. by multiplying the estimates for California (Table A5-10) by the ratio between the annual ballast water discharge in the U.S. and the discharge in California (19.6, from Table A5-1). The resulting estimates are entered in Table VI.E-2.

Onshore Cost - Ship Retrofit/Modification - California and United States

The method of calculation is the same for California and the U.S. The estimated number of ships needing to treat ballast water over the project period is 13,115 in California and 80,000 in the U.S. (Table A5-1). We assumed that half will be existing ships requiring retrofits, and that these will be completed during the first 5 years of the project period with an equal number each year. We assume the other half will be new ships with the modifications built in during construction, and that this will occur during the last 25 years of the project period with an equal number each year. Nearly all of the cost estimates in the literature for ship retrofit/modification are for retrofits; installing a modified ballast system in new ships will cost less than retrofitting existing ships (AQIS 1993b) and CAPA (2000) estimated that the cost could be an order of magnitude less. In these calculations we assumed that the cost for new ships will be half of the cost for retrofitting existing vessels.

The cost estimates in the literature for retrofitting existing ships are listed in Table A1-7. The estimates by Glosten (2002) and Brown and Caldwell (2008) are the most recent and provide more thorough engineering analysis than the earlier estimates. They were also explicitly designed to use pumps and pipes that are large enough to allow deballasting of the ship at berth in the time needed for cargo loading, and the Glosten (2002) estimates are further intended to be upper bound estimates for the types of ships they represent. Glosten's estimate for retrofitting an 869'-long oil tanker ($2.3 million in June 1, 2010 dollars) with a ballast pump capacity of 6,400 MT/h is a substantial outlier compared to Glosten's estimates for other ships (which range from $131,000 to $540,000) and compared to all the other retrofit/modification estimates (which range from $13,000 to $537,000). For this analysis, for the average cost of retrofitting an existing vessel we used the average of Glosten's and Brown and Caldwell's estimates excluding Glosten's tanker estimate; this average is $251,000.

Using these figures, the present value of the costs were calculated and entered as the capital costs for ship retrofit/modification in Tables VI.E-1 and VI.E-2.

Shipboard Cost - California and United States

Lloyd's Register (2010, Table 5) lists the cost estimates for shipboard treatment systems that were provided by the equipment developers and manufacturers in response to a questionnaire. The column containing these estimates is labeled "Installed Cost", but neither table nor text describe the basis for estimating the installation cost, and it is unclear whether installation costs are included in all cases. Unlike the ship retrofit/modification estimates in the literature, which were done by third parties (usually by engineering firms working on contract for government agencies) and were sometimes intended to be upper bound estimates, the shipboard treatment system costs were provided by developers or manufacturers who have a self-interest in providing low or lower-bound estimates in order to attract customer interest and perhaps investor interest. There is no mention of any effort by the Lloyd's Register authors to verify these estimates or assess their reasonableness, and at least some seem unreasonably low for the manufacture and installation of treatment systems approximately capable of meeting the IMO D-2 standards (for example, an estimate of $5,000 in capital cost for a 2,000 MT/h treatment system. which is equal to the wastewater treatment capacity needed to serve a fairly large city (Table A4-2)).

We estimated the average cost of a retrofitted shipboard treatment system from the eight treatment systems for which type approval is reported as received or pending in Lloyd's Register (2010) or ABS (2010), and for which capital cost estimates are available for both 200 and 2,000 MT/h systems (Table 5 in Lloyd's Register 2010) (Table A5-11). Capital costs for a 1,436 MT/h system (the estimated average ballast pump capacity, see Appendix 4) were estimated by linear interpolation. Linear interpolation will tend to underestimate the cost, since there are substantial economies of scale for most of these systems (i.e. the cost for a 2,000 MT/h system is less than 10 times the cost for a 200 MT/h system) so that the cost vs. capacity curve is concave downward. Operating costs were not provided for two systems; these were estimated by comparison to systems using similar processes. The average cost for a system was calculated as the interpolated capital cost plus the present value over the average lifetime of a retrofitted ship (12.5 years) of the operating cost times the average annual ballast water discharge per ship. We estimated different values for average annual ballast water discharge per ship in California and the U.S., by dividing the total annual discharge by the number of vessels estimated to be retrofitted in each of the first 5 years of the project period (1,312 in California and 8,000 in the U.S., see below), yielding annual discharges estimates of 9.300 MT/ship in California and 30,000 MT/ship in the U.S. We do not place high confidence in these discharge estimates, but since operating costs are small compared to capital costs, they are unlikely to have a significant impact on the overall cost estimate. The resulting estimates for the average cost of a retrofitted shipboard treatment system were thus similar in California ($861,000) and the U.S. ($869,000).

Table A5-11. Capital and operating costs for treatment systems for which type approval has been received or is pending. Figures have been adjusted to June 1, 2010 US dollars as described in Appendix 1B.

Treatment System	Capital Cost (200 MT/h)	Capital Cost (2000 MT/h)	Interpolated Capital Cost (1,436 MT/h)	Operating Cost/MT
Hi Tech Marine	150,800	1,609.000	1,152,000	0
Hyde Marine	231,300	1,207,000	901,000	0.02
NEI	250,400	673,800	541,000	0.13
NK	251,400	1,005,600	769,000	0.007
Oceansaver [1]	289,600	1,609,000	1,196,000	0.14
Optimarin [2]	291,600	1,287,000	975,000	0.02
Siemens	502,800	1,006,000	848,000	0.009
Techcross	201,100	603,400	477,000	0.003
Mean	271,100	1,125,000	857,000	0.041

[1] Operating costs for this filtration, electrochlorination, deoxygenation and cavitation system were not provided; we estimated them as the sum of the operating costs for the Siemens (filtration and electrochlorination) and NEI (deoxygenation and cavitation) systems.

[2] Operating costs for this filtration and UV system were not provided; we estimated them as equal to the operating costs for the Hyde Marine system (filtration and UV).

The remaining calculations were essentially the same as for the ship retrofit/modification costs. The estimated number of ships needing to treat ballast water over the project period is 13,115 in California and 80,000 in the U.S. We assumed that half will be existing ships requiring retrofits, completed during the first 5 years with an equal number each year, and half will be new ships with modifications built in during construction during the last 25 years of the project period, with an equal number each year. We assumed that the cost for new ships will be 90% of the cost for retrofitting existing vessels, due to reduced installation costs, though as noted it is not clear that all the Lloyds Register (2010) cost estimates include installation costs. The California and U.S. costs were calculated using the estimated average cost for a retrofitted shipboard treatment system and reported in §VI.E.3.

APPENDIX C: BIOSKETCHES

To be added