Glosten

SHORE-BASED BALLAST WATER TREATMENT IN CALIFORNIA

LITERATURE REVIEW

PREPARED FOR

DELTA STEWARDSHIP COUNCIL
SACRAMENTO, CALIFORNIA

24 NOVEMBER 2015
FILE NO. 15086.01
REV. -

PREPARED	CHECKED	APPROVED
Digitally Signed 24-Nov-2015		
RUSTY H. ROBERTS	**PETER S. SOLES**	**KEVIN J. REYNOLDS, PE**
ENGINEERING WRITER	PROJECT MANAGER	PRINCIPAL-IN-CHARGE

Table of Contents

Revision History

Section	Rev	Description	Date	Approved
1,2,5	P1	Preliminary release of Sections 1, 2, and 5.	9/4/15	KJR
All	P2	Preliminary release of literature review. All sections are included and updates are made to initially released Sections 1, 2, and 5.	9/9/15	KJR
All	–	Panel comments incorporated; literature review released for distribution.	11/24/15	KJR

Executive Summary

Marine vessels routinely uptake ambient sea or harbor water as ballast, transit to another port, and then discharge that ballast water. *Unfortunately, the resulting ballast water discharges have been linked to the introduction of aquatic invasive species and harmful pathogens*. In an effort to reduce or possibly eliminate further introductions, marine vessels are being required to manage ballast water discharges by a myriad of international, federal, and regional guidelines and rules. Vessels discharging in California will be required to meet an interim standard that is significantly more stringent than international and federal standards.

In response, there has been significant development work and commercial installations of treatment systems located on board marine vessels themselves. However, there is a lack of data to determine if the treatment systems that are being installed on board marine vessels are capable of meeting California's interim standard. *Shore-based ballast water reception and treatment is under consideration as an approach to meet the California interim standard.*

This literature review considers over thirty documents, authored in the last ten years, with insight on the feasibility of shore-based reception and treatment. Relevant findings are highlighted that may provide insight on implementing a shore-based approach to meet the California interim standard. Six of these studies offer original and substantial study on the subject:

- Brown and Caldwell (2007, 2008) – Section 2.1.
- Hilliard (2010) – Section 2.2.
- Pereira (2012) – Section 2.3.
- COWI (2012) – Section 2.4.
- King (2013) – Section 2.5.
- Ballast Water Treatment Boat (2013) – Section 2.6.

Brown and Caldwell (2007, 2008) reviews technical feasibility and provides planning-level cost estimates by developing concept designs for a barge-based system and marine vessel modifications. Hilliard (2010) uses geographical features and vessel traffic to consider implementation in the Caspian Region, focusing on port characteristics and vessel practices. Pereira (2012) develops a simulation model for vessel traffic and port operations at two major iron ore ports in Brazil to determine the required facility treatment rate and storage capacity that minimizes delays to vessel traffic and cargo.

COWI (2012) presents case studies for two Danish ports, considering variables such as treatment method, port of interest, vessel type, scope of services provided, and point of treatment. The study estimates the cost per ton of ballast water treated and the cost per treatment event for each case. King (2013) examines the economic feasibility of barge-based treatment as a contingency measure at the Port of Baltimore, considering both supply- and demand-side issues for implementation. BWTBoat (2013) takes a large-scale approach, reviewing two major shipping regions, Europe and Asia/Oceania. The study analyzes data to determine the number of marine vessels that exclusively operate in a particular region, and then determines the number of treatment units required to serve those vessels.

The characteristics and cost estimates of these six studies are tabulated as follows:

- Characteristics of ports, vessels, and treatment systems – Table 21.
- Summary of cost estimates – Table 22.

Key Themes

The literature can be broken into key themes relative to the feasibility of shore-based ballast water reception and treatment facilities in California.

Shore-based reception and treatment approaches

The majority of approaches considered in the past decade are mobile systems: retrofitted marine vessels or truck trailers outfitted with the necessary equipment for capture, treatment, and, in some cases, storage of ballast water. Mobile treatment approaches are discussed in Section 3.1.4. Additional approaches are:

- Constructing a land-based treatment and reception facility – Section 3.1.1.
- Sending ballast water to an existing waste water treatment plant – Section 3.1.2.
- Reception and reuse of ballast water – Section 3.1.3.

Relevant findings include:

- For a land-based facility, once the ballast water is collected it may no longer be considered “ballast water,” and thus different effluent restrictions might be applicable.
- The salinity of the ballast water may make use of an existing waste water treatment plant impractical, and requires careful review.
- Mobile approaches, marine vessel-based or land-based, offer significant flexibility to support the port operations of certain locations. Careful consideration of operating and transportation expenses should be considered for this approach.

Port logistics

Implementation of a shore-based treatment approach may have significant implications on the logistics of port operations, varying considerably on the treatment approach and the port’s characteristics. Several aspects of port logistics are discussed in Section 3.2:

- Vessel logistics – Section 3.2.1.
- Ballast water transfer – Section 3.2.2.
- Ballast water storage – Section 3.2.3.
- Ballast water treatment and storage – Section 3.2.4.
- Handling of residual slurry – Section 3.2.5.

Relevant findings include:

- Further research is needed to understand the extent that marine vessels discharge ballast water offshore during cargo lightering operations or while transiting to port, and the applicability of regulations on such practices.
- The extent and expense of new port infrastructure required will vary greatly depending on the reception and treatment approach and the particulars of the marine vessel ballasting practices for that specific port.
- Ballast water storage facilities can increase port operations flexibility and level ballast water discharge surges, but can significantly increase capital costs.

- Ballast water characteristics, such as salinity or transmittance, could be used to identify effective treatment technologies. However, it may not be possible to predict the characteristics given the variety of potential ports of origin for ballast water.
- It may be feasible to dispose of remaining sediments from the treatment process to a landfill. Appropriate regulations should be investigated.

Vessel modifications

Marine vessels intending to use shore-based reception and treatment approaches may require modifications, such as retrofitting a vessel's piping systems and providing a universal connection for transfer to shore-based infrastructure. Recently, shore-based approaches have been considered that may eliminate the need for such vessel modifications (Section 3.3).

Relevant findings include:

- Vessel modifications can range from tens of thousands to upwards of millions of dollars, depending on vessel type and pre-existing pumps and piping systems
- A reliable connection between the marine vessel and the shore-based approach is essential to prevent leaks of untreated ballast water.

Supplementary issues

The literature also identifies supplementary issues relevant to shore-based treatment approaches at California ports:

- Burden of responsibility for shore-based reception and treatment – Section 4.1.
- Shore-based treatment as contingency measure – Section 4.2.
- Repurposing of treated ballast water for household or agricultural use – Section 4.3.

Relevant findings include:

- Economic feasibility should consider the use of third-party contractors, rather than the port authorities, who may consider capital investments based on potential revenues.
- Economic feasibility, based on a contingency approach, may be uncertain if marine vessels continue opting to treat ballast water with shipboard systems.
- The transfer of treated or untreated water to desalination plants may have applicability for locations with small ballast water discharge volumes.

The literature on shore-based ballast water reception and treatment constitutes a small subset of the larger body of work on ballast water treatment. However, the applicable studies cover a wide range of implementation approaches and analytical methods. *These studies indicate that the feasibility of shore-based ballast water reception and treatment is heavily dependent on the reception and treatment approach, its compatibility with the characteristics of each considered port, and the particulars of the associated marine vessels.*

Section 1 Introduction

Marine vessels carry ballast water for multiple purposes, which include maintaining stability and trim, keeping hull bending moments below stress limits, keeping the propeller submerged, controlling hull depth and air draft, and ensuring adequate visibility from the navigation bridge. Some marine vessels, such as passenger ships and certain containerships, might only discharge ballast occasionally, in smaller volumes such as hundreds of tons, and have some flexibility in the amount and timing of those discharges. Other marine vessels, such as tankships and bulk carriers, must discharge large quantities of ballast water such as tens of thousands of tons, and in tightly defined sequence with cargo loading.

Shore-based ballast water reception and treatment is any combination of transferring, holding, or processing marine vessel ballast water through use of fixed or mobile facilities located on land or on another marine vessel. The objective is to ensure that no ballast water is discharged that does not meet water quality standards, including aquatic invasive species and potentially harmful pathogens. Although permitted within the international, federal, and state regulatory framework, there has been relatively little development of shore-based solutions. Most development has been focused on locating the treatment plants on the marine vessels themselves.

Advances in shipboard treatment solutions have motivated an increased interest in mobile, shore-based treatment approaches that implement similar technologies. Thus, the focus of the literature on shore-based treatment over the past decade has shifted towards mobile approaches rather than fixed land-based facilities. Several feasibility studies have been conducted to assess the economic and technical viability of a shore-based approach, mobile or otherwise, but no such facilities have been implemented to date.

Another notable trend in the literature on shore-based treatment is the investigation into shore-based treatment as a contingency option for shipboard treatment. Due to uncertain market conditions and relatively nascent technology, a certain percentage of ships may be unable to meet regulatory requirements; it has been proposed that shore-based treatment may offer a viable alternative for those vessels. Additionally, recent literature has envisioned implementing shore-based treatment on a fleet-by-fleet basis, rather than port-wide. Considerable thought has been given to how shore-based treatment may fit into a shipboard-dominant ballast water treatment market, but the body of work on the subject is still immature, and the feasibility studies conducted on shore-based treatment are preliminary assessments covering a range of implementation options.

1.1 Definitions, Abbreviations, and Units

General Definitions	
Ballast water	Water taken on by a ship to maintain stability in transit.
Ballast water management	The entire process of treatment and handling of a ship's ballast water to meet regulatory requirements and prevent spread of non-native species.
Ballast water exchange	The process of exchanging a vessel's coastal ballast water with mid-ocean water to reduce concentration of non-native species in accordance with regulatory guidelines.
Filtrate	Backwash water used to clean ballast water treatment filters that has been separated from any particulate matter.

Lightering	Cargo transfer between vessels, commonly practiced to reduce a vessel's draft before entering port.
Non-native species	Species that are not indigenous to a particular region. Non-native species can be introduced to marine ecosystems through a ship's ballast water. "Invasive" species are non-native species with the potential to cause harm to the environment or human health.
Treatment approach	A general method for implementing ballast water management, irrespective of the treatment technology utilized. Treatment approaches include mobile systems, land-based facilities, shipboard systems, etc.
Treatment technology	Specific technique for removal or inactivation organisms in ballast water e.g., UV disinfection, filtration, ozonation, etc.)
Residuals	Particulate matter collected from cleaning ballast water treatment filters.
Shore-based ballast water treatment	Ballast water management approaches that require support from shore-based infrastructure in order to meet ballast water treatment requirements. Such infrastructure includes: means of transferring ballast water to a land-based or another marine vessel facility for storage and/or processing. This also includes deployment of shore-based equipment and personnel for onboard treatment approaches.
Shipboard ballast water treatment	Ballast water management approaches that do not require support from shore-based infrastructure and are conducted entirely by a vessel's crew.
Slurry	Mixture of filtrate and filter residuals resulting from cleaning ballast water treatment filters.
Ballast Water Management Process Definitions	
Transfer	Ballast water transfer considers the logistics and equipment required to capture the ballast water from the marine vessel and transport it to a reception and treatment facility.
Capture	Capture is the method by which ballast water is transferred onto or off a marine vessel.
Transport	Transport is the method by which ballast water is moved post-capture from marine vessels to remote, non-mobile reception and treatment facilities – either land-based or otherwise.
Storage	Storage of ballast water includes provision of space and containment for ballast water, either pre-or post-treatment.
Treatment	Treatment includes any of the various methods to process ballast water such that it is suitable for discharge in compliance with applicable standards and regulations.
Discharge	Discharge of ballast water is the method by which post-treatment ballast water is disposed of in compliance with applicable standards and regulations.
Slurry Handling	Slurry handling includes all activities related to the storage, treatment, and discharge of filtrate and residuals collected from cleaning ballast water treatment filters.
Abbreviations	

IMO	International Maritime Organization
EPA	Environmental Protection Agency (US, unless otherwise noted)
USCG	United States Coast Guard
NBIC	National Ballast Information Clearinghouse
BWM	Ballast Water Management
BWE	Ballast Water Exchange
O&M	Operations and Maintenance
UV	Ultraviolet light
Units	
DWT	Deadweight tonnage
gpm	Gallons per minute. Any measurements quoted in gallons of ballast water per minute will also be shown in MT of ballast water per hour, or MT/h.
L	Liter
mg	Milligram
MT	Metric tons. One cubic meter of seawater is roughly equivalent to 1.025 MT, but this value varies depending on temperature and salinity of the water. In this report, conversions between volume and weight of seawater are merely approximate and assume 1 m^3 of seawater has a mass of roughly 1 MT, for convenience.
MG	Millions of gallons. Any measurements quoted in MG of ballast water will also be shown in MT of ballast water.
PSU	Practical salinity units.

1.2 Scope

This literature review is part of a larger project to assess the feasibility of implementing shore-based ballast water treatment in California ports to meet the state's interim performance standards for ballast water discharge. The review focuses on the types of shore-based treatment approaches proposed in the literature, along with associated assessments of port logistics and vessel modifications required to implement these approaches.

Vessels calling in California ports are required to maintain compliance with a currently shifting set of international, federal, and regional ballast water management requirements. These must be considered in developing shore-based solutions to avoid placing an operator unintentionally at odds with other requirements. To some extent, each of these regulations have various provisions for shore-based treatment approaches.

- The international convention, as adopted by the International Maritime Organization (IMO) in 2004, is well described in Gollasch (2007). However, as of 2015 the convention has not yet been ratified. In addition, there are ongoing efforts to improve the ballast treatment system testing guidelines, as well as efforts to mature and clarify compliance, monitoring, and enforcement practices.
- The relevant federal regulations are presented in CSLC (2014).
    - The US EPA is currently regulating ballast water under the 2013 Vessel General Permit, which includes numerical discharge standards applicable in California as

well as a timeline for vessel compliance. However, EPA has issued statements indicating that enforcement is a low priority due to the lack of US Coast Guard type approved treatment systems.

    - The US Coast Guard released its final rule for regulating ballast water discharges in 2012, 33 CFR § 151 and 46 CFR § 162. This includes numerical discharge standards, a means for type approving treatment equipment, and a timeline for compliance. However, the USCG is providing compliance extensions as it has not yet type approved treatment systems for vessel operators to install.

- California has published interim and final treatment standards and timelines as described in CSLC (2014). The implementation of the interim standard has been delayed to 2020 and the final standard to 2030 to allow more time for research and development to meet the state's standards.

This review considers literature within the last ten years that is relevant to shore-based ballast water treatment as a possible means for marine vessels calling in California to meet the state's interim standards. Within the literature, the following key themes are reviewed:

- Shore-based reception and treatment approaches.
- Port logistics of implementing shore-based treatment.
- Vessel modifications required for ships to transfer ballast to shore-based facilities.

There are several relevant subjects to the implementation of a ballast water treatment approach that, while widely discussed in the literature on shipboard ballast water treatment, are not considered in detail in the literature on shore-based ballast water treatment. These include:

- **Cross-contamination.** It is well understood that once water from a given port is taken-up into vessel's ballast water tank that this water will mix with sediment and residual water from previous ports. In this way, vessels must assume that even local water taken into a vessel ballast tank must be treated as a risk. In the same manner, ballast water being shifted to a shore-based facility will carry with it the same cross-contamination risks. This would be the same regardless of whether the transfer was to a truck, barge, or rail car, as well as to any shore-based tankage, hoses, and other apparatus. The primary literature discusses to some extent off-loading methods, but not cross-contamination.

- **Range of water quality characteristics.** The effectiveness of ballast water treatment technologies are heavily dependent on the salinity, turbidity, and organic matter content of the water being treated. A port implementing shore-based ballast water treatment must consider the range of water quality characteristics of ballast water being "imported" by the marine vessels the port services. For example, the freshwater port of Stockton receives ballast water that is from freshwater, brackish, and marine ports. For California ports handling a high volume of domestic and international trade, an exceptionally wide range of conditions must be anticipated. The US Environmental Protection Agency's Environmental Technology Verification Program (ETV) offers guidance on the "challenge water" quality characteristics that should be used during testing of ballast water treatment technologies (Table 1).

Table 1 ETV water quality challenge matrix for verification testing

Water type	Salinity	Minimum Water Characteristics
Fresh water	< 1 PSU	DOM[1]: 6 mg/L as DOC[1] POM[2]: 4 mg/L as POC[2]
Brackish water	10 - 20 PSU	MM[3]: 20 mg/L TSS[4] = POM + MM: 24 mg/L
Marine water	28 – 36 PSU	Temperature: 4 – 35 °C

[1]DOM/C: Dissolved organic matter/carbon
[2]POM/C: Particulate organic matter/carbon
[3]MM: Mineral matter
[4]TSS: Total suspended solids

- **Compliance monitoring.** The ability to test and verify consistent and compliant treatment of ballast water is considered essential to any management program. There continues to be significant work on various tools and processes related to compliance monitoring.
  - The methods of extracting representative ballast water samples is an area of examination. A recent workshop sponsored by EPA and USCG examined various means that have been developed on the US Great Lakes, California, Germany, and by the US Naval Research Laboratory.
  - Equipment providers such as Hach and Turner continue to develop, and in some cases sell, handheld devices that provide an indication of biomass or viability of organisms in sampled ballast water. While these have not yet been accepted as part of a regulatory process, they continue to be promising.
  - The self-monitoring of engineering parameters within ballast water treatment systems is under discussion at IMO relative to how systems are tested and approved. These requirements are likely to get more prescriptive such that treatment plants are more effective at alerting vessel operators when operating outside of proven parameters and logging such events for regulatory inspection.

1.3 Methodology

The literature review identified over thirty documents published in the last ten years, including peer-reviewed work, grey literature, conference proceedings, and vendor information, that provide substantive discussion of shore-based reception and treatment. From the literature considered, six studies were selected for detailed review based on their thorough examinations of shore-based treatment and relevance to the project: Brown and Caldwell (2007, 2008), Hilliard (2010), Pereira (2012), COWI (2012), King (2013), and Ballast Water Treatment Boat (2013).

Each of the six studies selected for detailed review was analyzed with respect to the key project themes. Additional attention was given to the criteria and standards by which each study assesses the economic viability of shore-based treatment. The six studies were then considered alongside the larger body of work on shore-based treatment to further assess the key project themes and identify any supplementary issues.

Section 2 Feasibility Studies of Shore-Based Ballast Water Treatment

This section summarizes the relevant methods and results of the six major feasibility studies conducted on shore-based ballast water treatment in the past decade. Each study is summarized in detail to provide background regarding the analysis that has been performed to assess shore-based treatment. Each study is presented in the following structure:

- Relevant background for the study.
- Methods utilized to assess shore-based treatment.
- Assessment of economic viability for the selected treatment approach (if applicable).
- Results and conclusions of the study.

Descriptions of the methods utilized in each study are organized by the three project themes:

- Shore-based treatment approaches
- Port logistics
- Vessel modifications

These themes offer a convenient lens with which to view the literature. However, the studies considered do not necessarily offer comparable levels of detail on each theme; this is reflected in the level of detail presented for each study herein.

Any opinions expressed in Section 2 of this review are those of the respective authors of each the reviewed studies. Comparisons, discussion, and critical analysis of the feasibility studies, as they pertain to the state of California, are presented in Section 3.

2.1 Brown and Caldwell (2007, 2008)

The Wisconsin Department of Natural Resources contracted the environmental engineering firm Brown and Caldwell to conduct a feasibility study of shore-based ballast water treatment for the Port of Milwaukee. The study was conducted in two phases, completed in October 2007 and August 2008, respectively.

2.1.1 Phase 1

2.1.1.1 Background

The Port of Milwaukee is located on the south shore of Lake Michigan, accessed by ocean-going ships via the St. Lawrence Seaway. On average, 85 vessels call the port annually during the eight months that it is open (April through December). The majority of the 85 calls to port are from ships unloading cargo, and thus taking on ballast water. Authors note that ships visiting the grain elevator are the ones most likely to discharge ballast water and thus are the primary concern for ballast water treatment at the Port of Milwaukee.

2.1.1.2 Methods

The first phase of the feasibility study included the following:

- Review of Port of Milwaukee site maps.
- Overview of utility and dock operations.

- Discussions with port staff on potential for ballast water discharge at the port along with potential locations for treatment.
- Review of current literature on ballast water treatment.
- Development of potential design basis for collection, storage, and treatment of ballast water.
- Analysis of information gathered on shipping movements and operations from published studies and the Port of Milwaukee.

In Phase 1 of the study, various alternatives to shipboard treatment are explored and consideration is given to several components of the ballast water management process, as shown in Figure 1. The cost estimates given in this report are planning-level estimates.

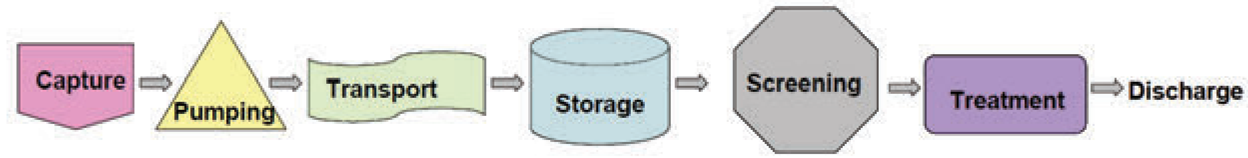

Figure 1 Process for collecting and treating ballast water (Brown and Caldwell, 2007)

The study develops design parameters based on the types of vessels that frequent the port. The study determines that grain carriers loading cargo at a rate of 600 MT/h for two hours are the limiting case for treatment time in the design criteria. Deballasting operations must not run longer than cargo operations, and the study determines that grain carriers represent the shortest cargo loading time among vessels that call the port. Other vessel types with greater cargo capacity are determined to have much longer stays in port (up to four days) and thus are not considered a limiting factor. The loading rate of 600 MT/h over a two-hour period corresponds to a ballast discharge rate of 3,000 gpm (~675 MT/h) for a tank capacity of 0.36 MG (~1,350 MT). It is noted that two ships may require simultaneous treatment, and to accommodate for this, a 0.5 MG (~1,900 MT) storage tank is adopted as a design criteria. A summary of design criteria are listed below:

- Assumed volume of ship's ballast water: 0.36 MG (~1,350 MT).
- Design discharge rate: 3,000 gpm (~675 MT/h).
- Treatment rate: 350 gpm (~80 MT/h).
- Design storage capacity: 0.5 MG (~1,900 MT).
- Time to treat entire storage volume: 2 days.
- Organism removal/inactivation efficiency: 90% or higher.
- Treatment system design life: 20 years.

After establishing the design criteria, the study evaluated each component of its ballast water management process: capture, pumping, transport, storage, screening (filtration), treatment, and discharge.

<u>Treatment Approach</u>

The study considers two approaches for ballast water treatment: sending water to the Jones Island Waste Water Treatment Plant (WWTP) and treating the ballast water onsite at the Port.

Jones Island WWTP

This facility is part of the Milwaukee Metropolitan Sewerage District (MMSD). The authors note that the efficacy of the treatment process at this specific site (chlorination must be evaluated using ballast water to determine if the appropriate standards can be met. Additionally, some pretreatment would be required, likely filtration, before sending the water to Jones Island. Ballast water may only be sent to the MMSD system during dry weather conditions, and thus an alternate storage option must be made available for wet weather. Some consideration is given to permitting requirements; particularly, only a pretreatment permit from MMSD would be required since the WWTP would ultimately discharge the ballast water. For a separate, onsite treatment facility, a permit from the Wisconsin Pollutant Discharge Elimination System WPDES) would be required to discharge ballast water into Lake Michigan.

Onsite Treatment

Each treatment technology is evaluated based on the design treatment rate of 350 gpm (~675 MT) and organism removal/inactivation efficiency of 90% or higher. Some consideration is given to the handling of residuals from onsite treatment, but no detailed procedure, cost analysis, or regulatory assessment is provided. Capital costs given for the four treatment technologies considered include additional contingency and provision for technical services, costs for replacements within the 20-year design life, and annual costs given in present worth at the time of the study's publication. The study calculated present worth using a 20-year life cycle and a 5% interest rate. Included in annual costs are estimated costs of energy usage, chemicals, labor, and equipment maintenance.

Four onsite treatment technologies are considered in the study. All four technologies include an initial filtration step:

- UV disinfection

The UV disinfection method presented in this study includes both course and fine filtration steps before UV treatment. The cost of this method is estimated to be $730,000. It is noted that, since the effectiveness of UV treatment is highly dependent on the UV transmittance of the ballast water, this method requires a certain amount of operational oversight to monitor the transmittance and make appropriate adjustments.

- Ozonation

Ozonation is not as sensitive to fine solids as UV treatment, and thus only a coarse filtration step is employed before ozonation with this method. The estimated cost is $920,000. The authors note that this method has greater complexity than UV and may require an oxygen supply tank.

- Membrane filtration

The method presented includes both course and fine filtration, and is followed by filtration via a microfiltration membrane that removes particles larger than 0.1 microns. For effective operation of the membrane, previous filtration steps must remove particles larger than 500 microns. The estimated cost of this method is $1,000,000. Though the method employs only mechanical separation techniques, the study notes that chemicals must be used to clean the filters periodically, but that the chemicals used do not affect the ballast water discharge. By physically removing the organisms, there is no concern of viable organisms remaining in the treated water. The study assumes that chemicals used in cleaning the filters will inactivate any residual organisms, thus eliminated disposal concerns.

- Hydrodynamic cavitation

Hydrodynamic cavitation uses pressure fluctuations in a fluid to cause implosion of vapor bubbles, which in turn produce a pressure pulse that inactivates the cell wall of organisms in the immediate vicinity. Course and fine filtration is employed before the final treatment step. This method requires treatment in batches, and thus another 0.5-MG (~1,900-MT) storage tank is required for the design. If an existing storage tank can be retrofitted for this purpose, the estimated cost is $1,100,000; otherwise, the authors note that the cost could be as high as $2,800,000 if an entirely new tank must be constructed. Advantages of this technology include:

- No chemicals necessary.
- Simple operation.
- Durable system due to few moving parts.

Appendix E of the study ranks the four treatment technologies with respect to numerous criteria, including efficacy of organism removal/destruction, chemical usage, energy consumption, and compliance with IMO standards. The authors find that there is very little differentiation between the four technologies with respect to the rating criteria, and conclude that the primary differentiating factor between technologies is cost.

Port Logistics

Capture

The following options are considered for ballast water capture:

- Diver-established connection between ship and shore.
- Machine-established connection between ship and shore.
- Ship surrounded with bladder or containment boom.
- Ship secured in a lock.
- Ship modifications to allow the onboard piping and pumps to connect to onshore pumps.

No direct investigation was performed on any of the above options, but the advantages and disadvantages for each option are considered. Due to safety concerns, the diver option is considered infeasible. Cost is likely prohibitive in the cases of the machine connection, containment boom, and lock options. Furthermore, liability issues inherent to the containment boom and lock options (due to risk of damaging the ship) present a serious concern. Thus, the study asserts that establishing a direct, onboard connection with the ship’s current ballast water system is considered the most viable option. The authors note that, ideally, a standard could be established to ensure that such modifications are compatible with other potential onshore treatment facilities.

Pumping

To move the ballast water from the ship’s ballast tanks to a transport system or holding tank, the design process considered employs a collection pumping system that includes two “trash-type” portable pumps with a flow rate of 3,000 gpm (~675 MT/h), each, which is comparable to typical shipboard ballast water pumps. These pumps would serve the ship from shore or a barge. Capital costs for the two pumps is estimated at $10,000, plus operations and maintenance O&M) costs.

Transport

Four options are considered for transporting ballast water from ships' tanks to the desired reception point (e.g., a holding tank or treatment facility): transport via pipelines, truck, rail car, and barge. The authors identify barge transport as the most feasible option, but note that depending on the dock location and discharge quantity, a multi-modal solution composed of the options presented below may be the most feasible.

Transport via Pipelines

The design basis assumes that piping would be established at all docks at the Port of Milwaukee for this transport option. Moreover, all pipes are assumed to be above ground, either along the dock itself or suspended by pipe racks or piers. It is estimated that 10,000 feet of 16-inch diameter pipe would be required to transport the 0.36 MG (~1,350 MT) of ballast water at the design flow rate of 3,000 gpm (~675 MT/h). The capital cost for the piping system (including pipe racks, pier connections, and necessary materials to protect pipe from weather damage) is estimated to be $2,600,000. It is noted that, while the pipes would always be available for collection, much of the system would sit idle throughout the year, which may not justify the sizeable investment required.

Transport via Truck

The study determines that, due to the typical capacity of a waste hauling truck (5,000 gallons), the time required and/or number of trucks necessary to transport ballast water to a treatment or storage location renders the method infeasible. The authors estimate that it would take over 72 hours for a single truck to transport 0.36 MG (~1,350 MT) of ballast and each transport event would cost at least $15,000, assuming the cost of hiring a truck is roughly $200 per hour.

Transport via Rail Car

Though many of the docks at the port already have rail infrastructure, the grain elevator – which would likely have the most need for ballast water operations – does not have direct rail access. This factor, along with the a 40-hour transport time for 0.36 MG (~1,350 MT) of ballast, required investment in a rail car, and the likely disruption to port operations, render this option infeasible for the Port of Milwaukee.

Transport via Barge

Barges commonly have capacity around 1.7 MG (~6,400 MT), allowing for significantly more storage capacity than the design capacity. Moreover, the ability to of a barge to approach a vessel from its seaward side minimizes the interference with cargo operations. It is noted that, rather than only serving as a transport option, ballast water treatment could take place on the barge, as well. For a barge dedicated to this purpose, an initial investment of $200,000 to $500,000 is required, along with tugboat fees for moving the barge (about $10,000 per movement).

Storage

The following options are identified for storing ballast water at the Port of Milwaukee.

Onsite Storage

The study identified various locations at the port where ballast water could be stored, noting that the port owns a currently unused 0.5-MG (~1,900-MT) storage tank. For this option, since the water would be stored above ground, the potential for freezing must be addressed. Storage in a barge is also included as an onsite storage option. As noted previously, a barge would need to be purchased specifically for this purpose.

Offsite Storage

The port could potentially transport ballast water to the MMSD inline storage system, a deep tunnel system that stores any excess water which cannot be treated immediately (e.g., during heavy rainfall). There are additional costs associated with pumping water out of the inline storage system and, importantly, this system could not be used during wet weather events. Moreover, this option requires removing all non-native organisms from ballast water before discharging to the inline storage system to eliminate risk of contaminating this system.

Discharge

The study considers two options for discharge of ballast water.

1. If ballast is treated at Jones Island WWTP, then discharge would be handled by the treatment plant and not the port.
2. For an onsite treatment facility, treated ballast would be discharged to directly to Lake Michigan. In this case, a permit from WPDES would be required. The study briefly notes that, though it would be possible to discharge treated water to constructed wetlands, the Port of Milwaukee does not have a practical location where such wetlands could be constructed.

Discharge of residuals from the filtration process is also considered, and the study notes that the residuals must be handled such that no viable organisms are discharged to Lake Michigan. Incinerating the residuals is suggested, but it is noted that detailed consideration of residuals handling is outside the scope of the study.

Vessel Modifications

The study does not consider vessel modifications in detail in Phase 1.

2.1.1.3 Results

The study highlights the design options that are "most likely" to be feasible:

- **Capture and pumping** – retrofit ships with universal connection to allow port-supplied pump to collect ballast water.
- **Transport and storage** – barge (or, possibly, some combination of other transport and storage options).
- **Treatment** – UV disinfection and ozonation are presented as the most cost-effective technologies; however, the study notes that all technologies considered (UV, ozonation, membrane filtration, and hydrodynamic cavitation are feasible, and that a treatment system could be installed either on a barge or on land. Moreover, it is reaffirmed that more testing is required to determine the treatment efficacy of the chlorination process used at Jones Island WWTP on ballast water.

No explicit recommendations are given for ballast water discharge, as this option is dependent on whether or not a WWTP is used for treatment.

The study asserts that shore-based treatment is a feasible approach for the Port of Milwaukee, and has the potential to offset investment by the amount of money saved compared to mitigating invasive species after their introduction into the Great Lakes. Finally, the study suggests that shore-based treatment could be implemented for use by ships with smaller volumes of ballast water and less incentive to invest in shipboard treatment, while ships with larger volumes of ballast water would be required to implement a shipboard treatment approach.

2.1.2 Phase 2

Following up on their Phase 1 work, Brown and Caldwell, along with co-author Bay Engineering, Inc., issued "Port of Milwaukee Off-Ship Ballast Water Treatment Feasibility Study Report, Phase 2" in August of 2008.

2.1.2.1 Background

Phase 2 is composed of the following:

- Concept design, capital cost estimates, and implementation time for vessel modifications.
- Concept design, capital cost estimates, and implementation time for retrofitting a barge for ballast water treatment.
- Concept design for ballast water treatment.
- Ballast water sampling plan.
- Consideration of social and economic impacts of this shore-based treatment approach.

2.1.2.2 Methods

The design criteria are updated from Phase 1 and are summarized below:

- Ballast capacity of design ships: 1.5 MG (~5,700 MT) and 4.7 MG (~17,800 MT).
- Discharge rate of design ships: 2,500 gpm (~560 MT/h) and 10,000 gpm (~2,250 MT/h).
- Treatment rate: 1,000 gpm (~225 MT/h).
- Treatment time per ship: Two days.
- Design storage volume (on barge): 2.7 MG (~10,200 MT).
- Treatment system design life: 20 years.

The design specifies two days between ship treatments (i.e., the treatment rate is sufficient to treat entirety of design capacity within two days).

For the design basis, two representative ships are selected: the *Federal Pioneer* and a larger, hypothetical ship. *Federal Pioneer* has ballast capacity of 1.5 MG (~5,700 MT) while the hypothetical ship considered has 4.7 MG (~17,800 MT). Conceptual drawings are developed for a single-hull barge with the design capacity of 2.7 MG (~10,200 MT).

Phase 2 builds on Phase 1 work to develop preliminary designs for vessel and barge modifications, as well as associated cost estimates.

<u>Treatment Approach</u>

Barge Design

The barge selected for this study is a single-hulled liquid cargo barge with the design storage capacity of 2.7 MG (~10,200 MT) and a cargo piping system capable of handling 10,000 gpm (~2,250 MT/h). A single-hulled barge is selected due to anticipated availability, as regulations entering into force soon after this study was conducted required that double-hulled barges be used for oil transport. Approximate dimensions of the barge are a length, beam, and molded depth of 300 feet, 65 feet, and 22 feet, respectively.

Ideally, the barge should retain as many existing systems as possible. This includes the oil cargo transfer system, all hose davits and cranes, and any existing generators, assuming they provide adequate power for the design requirements. Any superfluous systems and machinery should be removed from the barge.

If not currently installed, the following modifications to the barge are noted in the study:

- Two cargo headers, one port and one starboard, each with a capacity of 5,000 gpm ~1,125 MT).
- Two new, 12-in diameter cargo hoses to connect the ship's main deck flange to the loading flanges on the barge cargo headers.
- If necessary, a house structure could be constructed to accommodate the treatment equipment.

The design calls for electrical power on the barge provided by diesel generators. New diesel generators would need to be purchased if power requirements cannot be met with existing equipment. Additional details are provided in the study, along with piping and arrangement diagrams.

Shipyard time to modify the existing barge is estimated to be 12 days. This estimate assumes a 12-person crew working eight-hour days. Additional time may be necessary to transport the barge to Milwaukee and to clean and degasify the cargo tanks. Cost estimates for the barge are summarized in Table 3.

Technology Selection

The treatment technology chosen for Phase 2 is filtration plus UV disinfection. Cost estimates for the treatment unit are summarized in Table 3.

Authors emphasize that a wastewater characterization study, benchmark testing, and a pilot study of the treatment technology should be conducted before implementation. Additionally, it is noted that ballast water could potentially be treated at Jones Island WWTP, but no further consideration is given to this approach beyond that previously provided in Phase 1.

Port Logistics

Sampling Plan

The study includes a sampling plan developed to demonstrate compliance with IMO discharge standards. A brief summary of the plan is included below:

- Establish sampling points before and after treatment.
  - Redundant samples should be taken to ensure precision and accuracy.
- Collect adequate sample volume (possibly up to 1,000 liters).
  - A modified plankton net with 50-micron mesh and removal "cod end" could be used to concentrate samples, effectively reducing the sample volume.
- Note the following for each sampling:
  - Location, date, and time of sampling.
  - Person who performed sampling.
  - Dates the analyses were performed.

    - Analytic techniques used.
    - Date of and person responsible for equipment calibration.
    - Results of all required analysis.
- Analyze ballast water onsite for basic attributes:
    - Temperature, pH, dissolved oxygen, and residual chlorine.
- Perform bacteriological analysis.
- Analyze total biomass, typical viral and bacterial indicators such as coliform groups, streptococcus and enterococcus groups, actinomytes, pathogens, enteric viruses, fungi, viral hemorrhagic septicemia (VHS), and DNA markers, and known invasive species such as zebra mussels and spiny water fleas.
    - Possibly include planktons, periphytons, macrophytons, benthic macroinvertebrates, and fish.
- At a minimum, follow test procedures in 40 CFR § 136, or request to follow alternate test procedures as specified in 40 CFR § 136.4.
- Establish a quality assurance program for calibration and maintenance of test equipment.
- Retain all documented information on test procedures for a time period to be determined by WDNR.

Vessel Modifications

Two representative ships are selected to assess the necessary vessel modifications – the *Federal Pioneer* and a larger, hypothetic ship. A table summarizing the characteristics of each ship is reproduced in Table 2.

Table 2 Design ship characteristics and capacities (Brown and Caldwell, 2008

Characteristic	Smaller Ship *Federal Pioneer)*	Larger Ship (typical, but not specific)
Length (meters)	143	220
Beam (meters)	23	23
Depth of hull structure (meters)	13	14
Design draft below waterline (meters)	8.3	10
Number of ballast water tanks	18	30
Ballast water volume	1.5 MG (5,700 MT)	4.7 MG (17,800 MT)
Total ballast water discharge rate	2,500 gpm (~560 MT/h)	10,000 gpm (~2,250 MT/h)

By selecting multiple design ships, the study can express cost estimates as a range of values and highlight differences in modifications necessary for these to two ship sizes.

To move ballast water to the treatment barge, the piping system in this design is modified to discharge at the main deck. Ships typically discharge ballast water below the waterline; therefore, a tee fitting is added inboard of the sea valve that, when closed, allows ballast water to be redirected to a new overboard connection on the main deck. Additionally, the ballast tank stripping system (which does not operate simultaneously with ballast discharge) is tied into the new discharge branch to allow discharge to the main deck for this system as well.

For the smaller ship design, all ballast tanks discharge to a single location, located on either the port or starboard side. In the larger design, the port and starboard ballasting systems are independent of one another, and thus two independent connections are added to discharge to respective sides of the main deck. It is noted that the number of discharge points will vary from vessel to vessel, and is entirely dependent on the existing ballast water system. The study determines the least obtrusive route for the new piping on the *Federal Pioneer*, but notes that this will vary from ship to ship.

Requiring ballast to be discharged from the main deck rather than below the waterline adds additional pressure, or "head," that must be overcome by a vessel's ballast pumps. The study determines that the pumps installed on the *Federal Pioneer* are sufficient to pump ballast water to the main deck. However, this may not be the case for all ships, and must be determined on a case-by-case basis.

It is noted that all modifications must conform to the standards of vessel classification societies and any additional regulatory standards, and all materials must be selected to integrate with the current ballast system. Additional details are provided in the study along with piping diagrams and pump sizing curves.

The study estimates that the time necessary to complete the aforementioned retrofits ranges from 5 – 17 days, assuming 12 people work on the retrofit for eight hours each day. Depending on the size of the vessel, modifications required to connect to the treatment barge range from $60,000 to $204,000. This estimate includes construction, contingency, and technical services costs.

2.1.2.3 Economic Viability

Table 3 summarizes the estimated life cycle costs for the considered shore-based treatment method. To estimate the life-cycle costs of annual operating expenses, the study assumes a 20-year design life and a 5% interest rate.

Table 3 Estimated life cycle costs for shore-based treatment facility (Brown and Caldwell, 2008)

Item	Cost
Barge capital costs	
Construction of barge modifications[1]	$238,000
Technical Services for barge modifications	$71,000
Cost to transport barge from East Coast to Milwaukee[1]	$400,000
Cost of used, single-hull liquid tank barge[1]	$2,000,000
Treatment unit capital costs	
Treatment unit (Filtration + UV Disinfection)[2]	$625,000
Technical services for treatment unit	$188,000
Capital cost total	**$3,522,000**
Operating Costs	
Tugboat services	$4,391,000
Operations and maintenance costs (Energy usage, cleaning chemicals, labor, equipment maintenance	$2,025,000
Total life cycle cost	**$9,938,000**

[1]If a barge with the necessary modifications is leased, this cost may be reduced.
[2]Does not include wastewater characterization study and bench testing.

As noted previously, the study estimates that – depending on the size of the vessel – modifications required to connect to the treatment barge range from $60,000 to $204,000. This estimate includes construction, contingency, and technical services costs.

2.1.2.4 Results

The main results of the Phase 2 study are the development of the conceptual design and cost estimates summarized in previous sections. Suggestions for further research are provided as well, including:

- Perform waste water characterization study.
- Review present findings and determine financial and political feasibility of further actions for implementation of shore-based treatment.
- Implement a pilot test program for one or more treatment approaches to demonstrate performance and full-scale operating costs.
- Implement a pilot test program for implementation of ship modifications.
- Develop detailed engineering design of the system based on above actions.
- Monitor progress of proposed regulations.
- Determine the procedures and costs for residuals handling.
- Further investigate requirements necessary for discharge via WWTP.

Socioeconomic Considerations

The study calls attention to the possibility that the cost of ship modifications necessary to use a shore-based treatment facility may influence vessel operators to avoid ports mandating use of such a facility. The study notes that decreased shipping traffic could have serious implications on the region, such as loss of Port of Milwaukee jobs, increased costs to export goods from the port, and subsequent loss of area jobs and businesses due to increased export costs. It is reiterated, however, that implementing a shore-based solution could drastically reduce the amount of money spent on future mitigation efforts by preventing the establishment of invasive species from the outset.

2.2 Hilliard (2010)

R.W. Hilliard (InterMarine Consulting) and J.T. Matheickal (GloBallast) authored "Alternative Ballast Water Management Options for Caspian Region Shipping: Outcomes of a Recent CEP/IMO/UNOPS Project." Hilliard (2010) reports on conclusions drawn from a collaborative project between the Caspian Environmental Project (CEP), the IMO, and the United Nations Office for Project Services (UNOPS) conducted in 2006 (Hilliard and Kazansky, 2006). The project included information gathering on ships' ballast water practices, vessel characteristics, navigational features, and historic patterns of bioinvasions in the Caspian region. The study assesses the viability of various ballast water management approaches, and gives particular consideration to a shore-based treatment approach – a fixed, land-based treatment facility.

No cost estimates nor detailed designs of the proposed land-based treatment facility are developed in the study. However, the study's examination of geographical and operational features of Caspian Region shipping provides very useful insight into how such features may determine the feasibility and design of a land-based treatment facility.

The study concludes that a shore-based treatment approach has the potential to be a cost-effective ballast water management approach for the region, provided the treatment facility be located at a port that "provides convenient access, bunkering, supply, and maintenance services to all vessels entering the Lower Don."

2.2.1 Background

The shipping region considered in the report includes the Black Sea, the Caspian Sea, and their connector, the Volga-Don Waterway (VDW). From east to west, the VDW is composed of the Sea of Asov, Asov-Don Sea Canal, Lower Don, Tsymlyanskoye Water Reservoir (TWR), Volgo-Don Shipping Canal, Lower Volga, and the Volgo-Caspian Canal. The VDW also connects with waterways that link Moscow and the Baltic Sea, which are referred to collectively as the Unified Deep Water System (UDWS). A map of VDW is reproduced below.

Figure 2 Main sectors and regional ports of the Volga-Don Waterway (Hilliard and Kazansky 2006 .

2.2.1.1 Characteristics of River-Sea Ships

"River-Sea" ships of the Caspian Region are a mix of vessel types with build dates from the 1960s to newly built. A large proportion of River-Sea ships in the region are more than 20 years old. The defining feature of River-Sea ships is that they are dual-classed vessels that may operate on short sea and protected coastwise routes as well as inland waterways, with corresponding dual displacement, deadweight tonnage, and ballast water capacities for voyages at sea draft (3.5 to 4.5 meters) and UDWS draft (3.5 meters or less). Ballast water reference forms (BWRFs) were distributed to River-Sea ships traveling both east-west and west-east voyages along the VDW during the Summer of 2006. Eighty-eight BWRFs were returned by operators of at least eighteen different vessel types.

Due to age, many River-Sea ships can no longer be classed for international short-sea voyages. The commercial life of such ships is limited and, for this reason, many ship owners may not be willing to invest in shipboard ballast water treatment approaches. Moreover, all River-Sea vessels face challenging space and weight constraints due to the shallow draft requirements of the UDWS, and so shore-based treatment may be appealing to vessel owners looking to reduce weight and/or increase available machinery space.

2.2.2 Methods

2.2.2.1 Treatment Approach

Hilliard (2010) considers a land-based treatment facility that would serve the entire Caspian Region. The authors cite Hilliard et al.'s previous study (Hilliard and Kazansky, 2006), which includes a ranking exercise to determine if such a facility warrants further investigation. The more widely acknowledged points include:

- A shore-based treatment approach is most feasible for ships that are dedicated to particular routes or ports.
- Shore-based treatment would only be feasible if a sufficient number of ships requiring it remain in the regional shipping fleet for 15-20 years, and if delays due to treatment are minimized.
  - It is suggested that regulations to encourage or demand use of a shore-based facility could alternately provide feasibility.
- Ships that use the facility will likely require retrofits to increase pumping capacity, modify piping systems, and install a universal connection to the shore facility.

The particular features of the Caspian Region and the vessels that frequent it play a very important role in assessing the viability of a shore-based treatment approach.

- The natural stopgap of the locks between the Lower Don and TWR suggests the point past which no untreated ballast water should be carried.
- Treating ships' ballast water and replacing it with pre-treated ballast before crucial navigational features, such as the often-rough waters of the TWR, gives ships the freedom to adjust ballast conditions accordingly to ensure safe transit.
- Ship congestion due to seasonal waterway closures would place higher stress on a shore-based facility, requiring capacity to service several ships at once to avoid delays.

A rough outline of the necessary infrastructure for the proposed land-based facility is discussed. Based on the region's shipping volume, the study selects a storage capacity of 6,000 MT and a treatment rate of 2,000 MT/day. At this capacity, ballast water could be collected for multiple days without treatment in case of an unexpected shutdown of the treatment system. Additional storage capacity would be needed to store pre-treated ballast water, though no estimates are given.

The type of treatment technology selected for a facility in the Caspian Region is highly dependent on the characteristics of the region's water. High turbidity and sediment pose challenges for filtration/UV and reverse osmosis/membrane filter treatment technologies. Low salinity and water temperature pose challenges for electrolysis and heating methods, and prevent the natural decay of toxicants.

The study notes that the results of their initial ranking exercise, which scored shore-based treatment versus existing shipboard treatment using a matrix of 13 operational features, indicated that shore-based treatment ranked the highest. However, it is noted that the "first-pass preliminary ranking" was performed in 2006, and significant advances in technology of shipboard systems have been made since.

2.2.2.2 Port Logistics

Considerations for Navigating the Volga-Don Waterway

The features of the waterways in the Caspian Region are an important factor in determining viable ballast water management approaches. The following is a brief summary of the factors considered in the study:

- Low salinity of Caspian Sea and adjacent waterways.
    - The Caspian Sea has a relatively high threat of the introduction of non-native species due to the similarly low salinities of the neighboring Black and Baltic Seas, and their respective connecting waterways.
    - Increasing the salinity of ballast water may be an effective treatment technology.
- Low level of halide ions in Caspian Sea and adjacent waterways.
    - Treatment methods that employ electrolysis to produce bromine and chlorine oxidants are hindered by the low concentration of such halides in the Caspian Region.
- Shallow, unprotected approaches to the VDW.
    - Frequently, ships approaching the VDW need to discharge ballast water to meet draft requirements. However, the wind-wave conditions on such approaches (the Sea of Asov approaching the VDW from the Black Sea, or the Astrakhan Outer Roads approaching the VDW from the Caspian Sea), make discharge a difficult and potentially dangerous operation.
    - For the same reasons, ballast water exchange (BWE) may not always be practicable before entering the VDW.
- Wind-wave conditions on the TWR.
    - The TWR has relatively large wind-waves that often necessitate that ships take on ballast to increase stability. Approximately 10% of eastbound respondents to the BWRF reported doing this. This high turbidity water mixes with the existing ballast water in the tanks and makes treatment more difficult. Moreover, taking on additional ballast complicates the navigation of the sections of the waterway that require a shallow draft.
- High turbidity ballast water.
    - Several sections of the VDW are shallow (resulting in low underkeel clearances), and have high turbidity due to wind waves, surge currents, spring floods, silty sand shoals, and mud banks. Any ballast water uptake from this waterway would be difficult to treat via UV disinfection, which requires high UV transmittance for effective treatment, and would demand more rigorous filtration methods than would be necessary for treatment of ballast water with a lower density of sediment and suspended solids.
- Locks between Lower Don and TWR.

  - Currently, these locks provide a barrier for the natural spread of freshwater species between the Black and Caspian Seas. To insure that invasive species are not spread between these regions, no untreated ballast water should be allowed to pass through the locks.
- Seasonal ice formation.
  - The VDW is not operational during frozen winter months. Just before the waterway's closing and shortly after its opening, vessels must be escorted by tugs and ice breakers to ensure safe passage. To minimize number of escort trips, each escort leads a large convoy of vessels. This practice may result in significant congestion at the proposed land-based treatment facility and would likely cause further delays to shipping activities and cargo movement.

Regional Ballasting Operations

The study found that westward cargo movement (exports) dominated eastward (imports). Thus, a large volume of ballast water enters the region from ships traveling eastward to load cargo (and discharge ballast) in the Caspian Region. The figure below is a summary of ballast water movement provided by the authors.

Table 4 Total estimated BW moved to and from the Caspian Sea from 1 April to 20 September 2006 (Hilliard and Kazansky, 2006)

	To Caspian		From Caspian			
Direction	MT	%	MT	%	**Source or Destination**	**% of Total BW**
Eastbound (VDW)	267,360	95.2%	–	–	from SoA, BS, Med ports	81.3%
Southbound (VBW)	13,420	4.8%	–	–	from Baltic ports	4.1%
Westbound (VBW)	–	–	34,200	71.2%	to SoA, BS, Med ports	10.4%
Northbound (VBW)	–	–	13,820	28.8%	to Baltic ports	4.2%
Totals	**280,780**	**85.4%**	**48,020**	**14.6%**	**328,800 MT**	**100%**

The relatively low percentage of incoming ballast water from the north is due to bottlenecks in the northern Volga that will not be resolved until modernization programs are undertaken on the waterway. The study notes that current BWE practices in the region are ineffective in reducing threats due to the following:

- Approaches to the VDW where BWE occurs are not free of native biota nor potentially invasive species.
- Strong winds and rough seas in the approaches to the VDW may disrupt or prevent BWE.
- Not all ships follow the current BWE requirements.
- High density of sediments and associated organisms are collected in the approaches to the VDW.
  - Sediment that cannot be pumped out of the ballast tanks remains along with unwanted organisms.

As noted in the previous section, many ships must take on additional ballast in the TWR, and the authors note that conversations with ships' crew indicate that ballast water discharge or uptake at various points along the VDW may occur more frequently than the BWRFs indicate.

2.2.2.3 Vessel Modifications

The study does not consider vessel modifications in detail, but notes that ships planning to utilize a shore-based treatment approach will likely require retrofits to increase pumping capacity, modify piping systems, and install a universal connection to interface with the facility.

2.2.3 Results

The study determines that trade in the Caspian Region is likely to grow and internationalize, though westward exports will continue to be the dominant shipping pattern. Thus, the primary vector of ballast water movement is eastward, via unloaded ships arriving to take on exports. In light of this, the study determines that the most effective method to prevent non-native species from entering the Caspian Region is to prevent any unmanaged ballast water from traveling east of the locks at the head of the Lower Don (near Volgodonsk) that provide a natural barrier to eastward travel of biota. Therefore, the proposed land-based facility should be positioned west of the locks on the Lower Don, ideally at an established port such as Azov or Rostov-on-Don. The facility envisioned in the study would receive and treat ballast water from ships entering the VDW and resupply the ships with pretreated ballast water. Ships that replace their ballast water with treated water from this facility would then be free to adjust their ballast for stability purposes after passing through the locks, as is frequently practiced in the TWR and shallow-draft sections of the VDW.

Older River-Sea ships are the most likely to use the land-based facility, as investing in shipboard treatment may not be cost-effective for such vessels. It is noted, however, that even for newer River-Sea ships conducting international trade, limited machinery space and power availability may encourage the use of such a facility. However, the larger ballast capacity of these vessels would result in longer delays at a treatment facility.

As previously noted, preliminary ranking in Hilliard and Kazansky (2006) awards the top score to a shore-based treatment approach. The study notes, however, that technology has evolved since this ranking and that the factors considered in the study are unique to the Caspian Region. Nevertheless, the authors emphasize that a shore-based treatment approach warrants further investigation.

2.3 Pereira (2012)

Pereira et al.'s "Onshore ballast water treatment: A viable option for major ports," develops a discrete events simulation model to evaluate on-shore treatment feasibility at two iron ore ports in Brazil. Discrete events simulation involves deconstructing a complex system into well-defined events that occur in a precise order. A graphical representation of the Pereira's model is reproduced in Figure 3. The model is validated against real data collected from the two ports and considers arrival, berthing, loading, deballasting, and treatment processes.

The study concludes that berth occupancy and vessel queuing are not affected by shore-based treatment when compared to normal operations. For a single port (Port of Tubarão), it is feasible to treat all 596 anticipated vessel arrivals per year with one treatment system. The authors argue that this demonstrates the economy of scale afforded by shore-based treatment, considering that shipboard treatment would require 596 treatment systems to service the same number of ships.

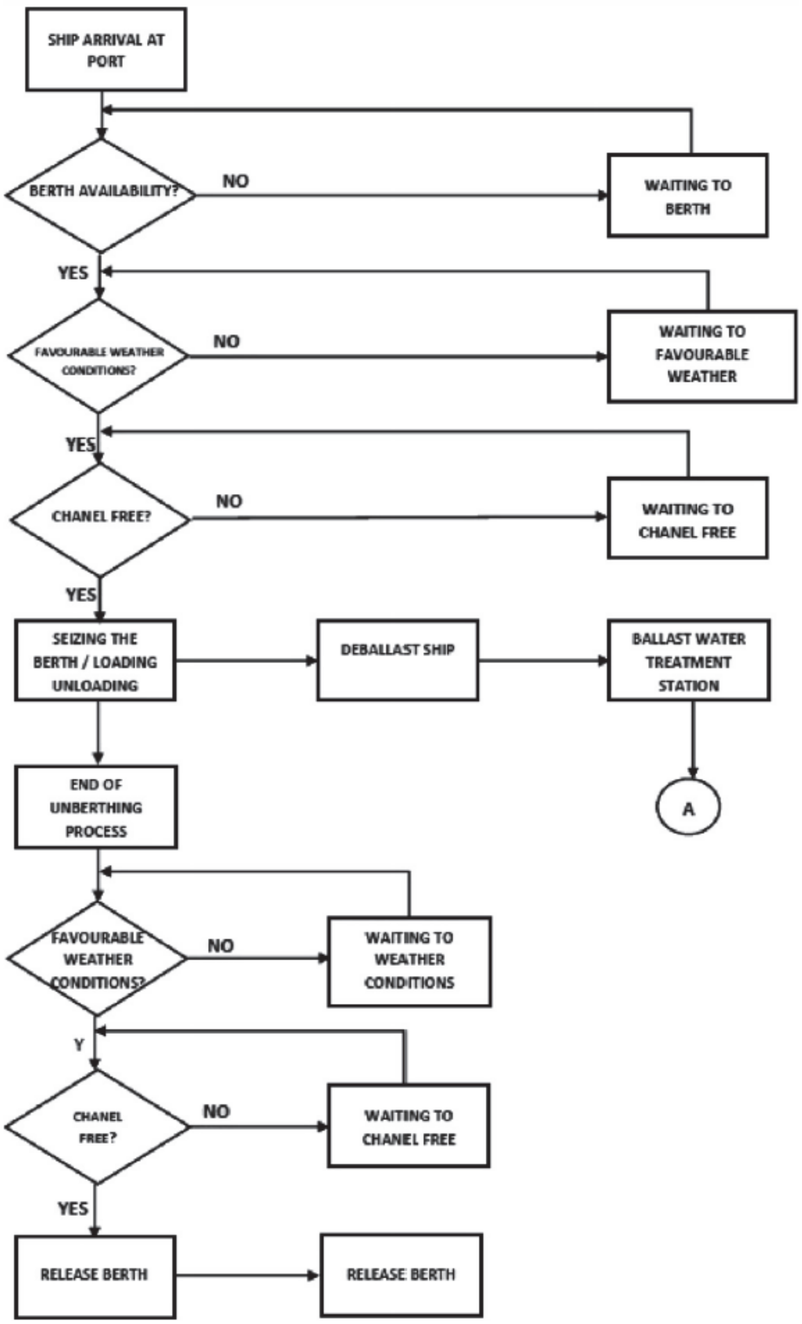

Figure 3 Graphical representation of discrete events simulation model in Pereira, 2006.

2.3.1 Background

The two ports examined in the study are the Port of Tubarão and the Port of Sepetiba. The Port of Tubarão is located in the city of Vitória, in the state of Santa Catarina, Brazil. The port has three berths, two of which can serve ships of 200,000 DWT or less and the other serves ships with a capacity of 300,000 DWT or greater. Generally, ships that visit the Port of Tubarão range from 40,000 DWT up to 400,000 DWT. The port moves 90,000,000 MT of cargo and receives 25,000,000 MT of ballast water, annually.

The Port of Sepetiba is located in Rio de Janiero. Though several types of vessels call to the port, two distinct terminals receive iron ore imports. This study considers one of those terminals, which operates with one berth and receives ships ranging from 60,000 to 200,000 DWT. When reference is made to the Port of Sepetiba in this study, it is assumed that only this terminal is being considered, unless otherwise stated. The port moves 25,000,000 MT of cargo and receives more than 7,500,000 MT of ballast water, annually.

2.3.2 Methods

2.3.2.1 Treatment Approach

Pereira (2012) does not consider an explicit type of shore-based treatment approach, but rather considers only abstracted details such as treatment rate and storage capacity.

2.3.2.2 Port Logistics

The study develops a discrete events simulation model to study the port operations of a shore-based treatment approach. The discrete events simulation model developed in the study is called "TRANSBALLAST," but will be referred to herein as "the model." The model takes into account the following variables:

- Transportation demand of the port.
- The classes of ships berthing at the port.
- Ship navigation in the access channel.
- Berthing and unberthing operations.
- Berthing time.
- Time before operation.
- Connection of pipelines, etc., involved in ballast transfer.
- Cargo loading rate.
- Deballasting rate.
- Ballast treatment rate.
- Ballast water storage capacity at the port.

A probabilistic distribution is attributed to each variable. This incorporates an element of randomness into the system, as might be expected in practical port operations. The authors describe the model as an "input and output" type, where input data are incorporated to obtain specific outputs:

- Annual transportation demand attended.
- Volume of ballast treated.
- Waiting time and average number of ships in queue.
- Berth occupation rate, lay days, and port services level.

The simulations model the ports' operations over a ten-year period and are replicated ten times to increase the level of confidence in the output data. Two important assumptions included in the model are:

1. Cargo is always available in port for loading
2. Rate of ballast water transfer is equal to the pump capacity on ship of interest.

The model accounts for typical cargo loading and deballasting procedures. Specifically, cargo operations in a particular hold only move to the next hold when both deballasting and cargo loading have completed in that particular part of the ship. Delay time due to deballasting is then calculated by adding up the instances in which cargo loading is suspended while deballasting continues.

To validate the model, simulations are run for both ports and compared against real, collected data to determine if the model emulates typical port operations. Table 5 provides a brief summary of the relevant data used.

Table 5 Summary of data collected for the Port of Tubarão and the Port of Sepetiba (Pereira 2012)

	Port of Tubarão	Port of Sepetiba
Annual cargo demand	90,000,000 MT	25,000,000 MT
Estimated annual ballast volume discharged	27,000,000 MT	7,500,000 MT
Estimated annual vessel calls	596	162
Length of ship stay	Variable: ~ 2 to 20 days	Variable: ~ 4 to 14 days

In the validation simulation, treatment rates, collection tank capacities, and deballasting rates are chosen to be sufficiently high as to not become limiting factors in the simulation. The validation simulation determined that port operations were not affected by the addition of a treatment system: cargo operations occurred per normal and the length of ship stay did not increase.

After validating the model, four simulation scenarios are selected that increase the percentages of the largest class of vessel that visits the Port of Tubarão. Table 6 shows the current breakdown of ships that call to both ports.

Table 6 Composition of vessels calling Tubarão and Sepetiba (Pereira 2012)

Ship Type	DWT	Port of Tubarão	Port of Sepetiba
Handymax	40,000	5%	0%
Panamax	70,000	10%	3%
Small Cape	100,000	0%	0%
Cape	150,000	50%	97%
Large Cape	180,000	25%	0%
Very Large Cape	250,000	10%	0%

The scenarios examine increasing percentages of very large oil carrier (VLOC) ships of 400,000 DWT that visit the Port of Tubarão:

1. Base-Alternative – assumes current demographic of ships (both Tubarão and Sepetiba are included in this scenario)
2. 5% VLOC (Tubarão only)
3. 10% VLOC (Tubarão only)
4. 15% VLOC (Tubarão only)

In Scenarios 2 – 4, it is assumed that the same number of ships visit the Port of Tubarão per year, but that a subset of the next largest class size of ships is replaced by the corresponding percentage of VLOCs.

All four simulations used the following criteria:

- Meet all cargo and deballasting demand with the minimum treatment rate and storage capacity.
- Ensure that berth occupation rates and queues are consistent with the validation condition.

2.3.2.3 Vessel Modifications

Pereira (2012) does not discuss the vessel modifications necessary to utilize the suggested shore-based treatment approach.

2.3.3 Results

In all scenarios, the simulations demonstrated that the treatment process had minimal impact on total vessel time in port. Average waiting times due to deballasting ranged from less than a minute (Base-Alternative) to just over five minutes (VLOC 15%) per ship. Queuing times remain relatively constant over all scenarios simulated. All ships visiting the ports are attended.

In each scenario, the minimum tank capacity necessary to attend all ships is 40,000 MT and the minimum treatment rate is 5,000 MT/h.

The study uses a novel approach to assessing the feasibility of shore-based treatment. The authors note that, since no shore-based treatment facilities currently exist, discrete events simulation is a valuable tool for assessing feasibility. A strong case is presented that, operationally, a shore-based ballast water treatment facility can be implemented without introducing undue delay. The study finds that providing sufficient ballast storage capacity and treatment rate onshore are critical factors to prevent disruption to normal cargo operations, assuming ballast is transferred from the ship at a rate roughly equal to cargo loading.

2.4 COWI (2012)

The Danish consulting company COWI A/S was contracted by the Danish Ship Owner’s Association, Maersk, DFDS, and Danish Ports to conduct a feasibility study for shore-based ballast water treatment using mobile treatment units. The study examines two ports in particular, the Port of Esbjerg and the Port of Fredericia. Six business cases representing a mix of vessels served, types of mobile treatment, and ports of interest are evaluated. For each, a financial analysis is performed to estimate both the cost per ton of ballast water treated and cost per vessel call.

The study determines that the most operationally feasible and cost-effective business case considered involves treating a particular fleet of vessels – DFDS-operated freight ferries – with a truck-based mobile treatment unit in each port of call. The fixed vessel schedules and high volume of ballast treated in this scenario results in the lowest cost of the shore-based approaches considered.

2.4.1 Background

The Port of Esbjerg and Port of Fredericia are located on the west and east coast, respectively, on Denmark’s Jutland Peninsula. The Port of Esbjerg receives 1,175 vessel calls per year, mainly from RoRo freight ferries, operated by DFDS and Sea Cargo, and service ships that supply offshore platforms in the North Sea. Based on feedback from DFDS chief officers, the average ballast discharge at the port is 300 MT per vessel call.

The Port of Fredericia receives a wider array of vessel calls than the Port of Esbjerg, including crude oil tankers, container ships, RoRo freight ferries, small tankers, and general cargo ships.

In total, the port sees 520 vessel calls per year. The study assumes the same average ballast discharged as assumed for Esbjerg (300 MT per vessel call).

The study selected the Port of Esbjerg and the Port of Fredericia due to the nature of their operations. The former services mostly vessels on fixed routes between a select number of ports and the latter services a wider variety of vessels with more variation in terms of service routes and ports of call. Both ports have sufficient space for treatment units and storage tanks and possess relatively deep navigation channels such that ships do not need to discharge ballast to reduce draft when approaching the ports.

Figure 4 Map of Jutland with Esbjerg and Fredericia marked (adapted from Wikimedia Commons)

2.4.2 Methods

The study considers the following variables:

- Port of interest
    - Port of Esbjerg, Port of Fredericia, other regional ports.
- Onshore treatment method
    - Barge-based or truck-based (referred to as "mobile unit" in the study) treatment unit treats ballast water upon vessel arrival.
    - Supplying treated water to vessels at departure.
- Scope of services provided
    - Operator services all ships calling to port regularly.
    - Operator services only one fleet of ships calling to port.
    - Operator services one fleet of ships and at all corresponding ports of call.

These variables are encapsulated in the six business cases selected, which are summarized in Table 7.

Table 7 Summary of business cases in COWI A/S (2012)

Case	Port	Treatment Method	Scope of Services
A-1	Esbjerg	Mobile unit	Operator handles all ships that regularly call to port
A-2	Esbjerg vessels and corresponding ports	Mobile unit	DFDS contracts stevedore to handle all DFDS ships on North Sea routes and service ships calling to port
A-3	Esbjerg	Mobile unit	Danbor (stevedoring company handles all service ships calling to port
A-4	Esbjerg	Barge	Operator handles all ships that regularly call to port
A-5	Esbjerg vessels and corresponding ports	Provide treated ballast at port of depature	DFDS contracts stevedore to handle all DFDS ships on North Sea routes and service ships calling to port
B-1	Fredericia	Mobile unit	Operator handles all ships that regularly call to port

2.4.2.1 Treatment Approach

The study develops a conceptual design for a mobile treatment unit suitable for placement on either a truck or a barge. The design forms the basis for the financial analysis conducted for each case study. The unit includes a commercial treatment system from Danish manufacturer DESMI A/S. The authors note that, at the time of the study's publication, the unit is "under testing by the relevant authorities." The treatment unit combines filtration and UV disinfection and has a capacity of 300 MT/h, in line with the estimated average discharge rate for vessels calling at the ports of interest.

Specifics for the mobile unit are provided and summarized as follows:

- Unit: 20-ft standard shipping container mounted on a 40-ft flatbed trailer.
- Power consumption: 90 kW.
  - Due to limited power supply at the ports of interest, a generator is to be mounted on the trailer to supply the unit.
- Connection to ship: 8-inch hose with a dry disconnect coupling DDC).
  - Fixed part of DDC to be installed on discharge pipe on the side of ships using the unit.
- Storage: 4-m^3 tank to receive backflushing slurry from filters.

Figure 5 and Figure 6 show the general layout of the treatment unit. The study also specifies that a 32-m^3 reception tank with agitators for reception and chlorination of residual slurry from the filter backflush be utilized on location at the port. Post-treatment, the slurry is to be stored in a 150-m^3 storage tank prior to discharge.

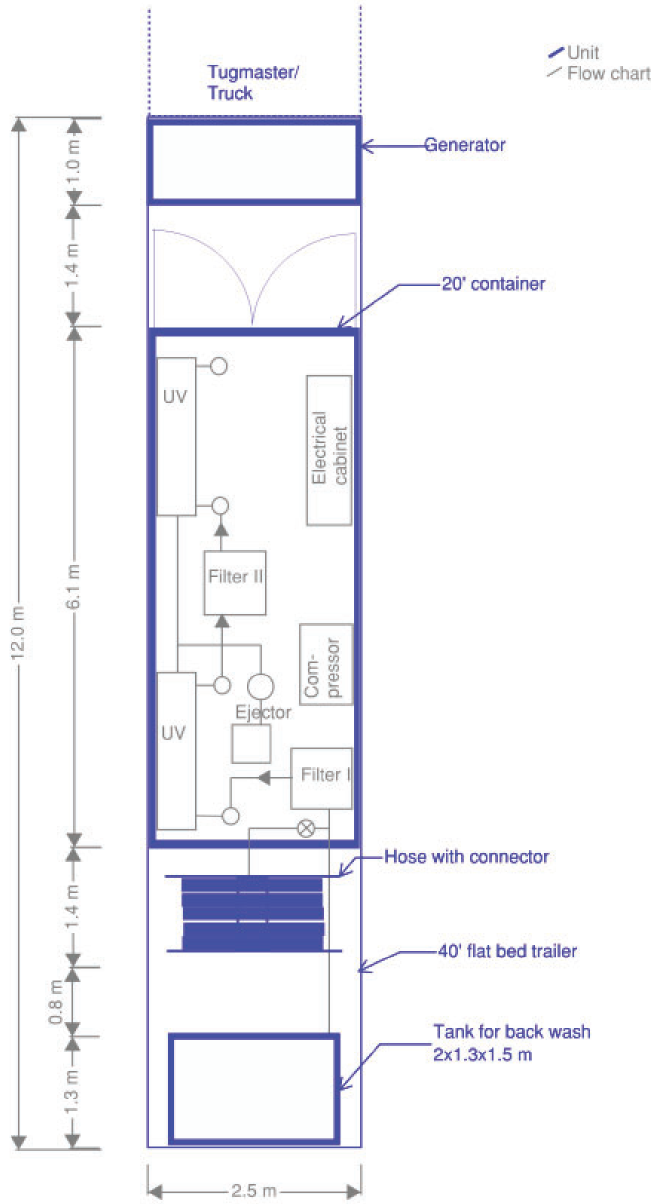

Figure 5 Arrangement of mobile treatment unit (COWI A/S, 2012)

Figure 6 3D sketch of mobile treatment unit (COWI A/S, 2012)

2.4.2.2 Port Logistics

Treatment Operations

Mobile Unit

The mobile unit can be connected to a truck and hauled to the appropriate berth for treatment. An additional unit can also be employed as a reserve in case of maintenance on the primary unit or abnormally busy periods at the port.

The study outlines how the treatment process would occur when a ship arrives needing treatment:

- Prior to arrival, the ship contacts the treatment operator to request treatment.
- Upon arrival, the unit is transported by truck and parked next to the vessel.
- A winch is used to hoist the hose up to the ship's discharge connection and connected via the DDC.
- Ballast is pumped to the treatment unit at a rate of 300 MT/h, as controlled by valves on the ship.
- Filters in the treatment unit are backflushed during treatment and the residual slurry pumped (via hydrocyclone) to the slurry tank on the mobile unit.
- After treatment is completed, the hose is disconnected from the ship and reeled back onto the trailer.
- Unit is moved back to reception tank, into which the slurry is pumped and then treated via chlorination.
    - Chlorination occurs over 24-hour period.
- Slurry is pumped into storage tank to settle; the treated water is drained off after separation.
- When tank is full, the concentrated sediment is taken to a reclamation or disposal site (see "Discharge," below).

The entire treatment process is estimated to take 1.75 – 2 hours, assuming that the average amount of ballast discharged per ship is 250 MT. Table 8 gives a breakdown of this estimate.

Table 8 Estimate of the duration of treatment operations (COWI A/S, 2012)

Transporting the unit to the ship	10 min
Connecting the hose to the ship	10 min
Treatment	50 min
Disconnecting hose and transport to slurry tank	15 min
Pumping slurry into reception tank	10 min
Return to base, cleaning, etc.	15 min
Total time	**110 min**

At a maximum, the mobile unit could serve four ships during an eight-hour shift. If demand exceeds this value, the reserve unit could be used.

For the Port of Esbjerg and the Port of Fredericia, the study found that parking the mobile unit next to ships at berth would cause no major issue with cargo loading or other port activities. At ports that use traveling container cranes to load cargo, however, a mobile unit may pose an interference.

It is noted that if parking space for the unit is not available, the unit could potentially be driven onboard for treatment; though, depending on the vessel type, this would likely hinder cargo operations.

Barge

For a barge-based unit, the treatment specifics are identical to the mobile unit. Of course, rather than transporting the equipment by truck, a barge is used. This method offers easier access to ships and additional space for equipment and storage tanks. However, the cost for a barge and necessary modifications well exceeds that for a trailer and truck.

The study notes that this service could be coupled with other barge-based services already conducted at many ports, such as the Port of Rotterdam. Moreover, a barge could be used at berths that are not readily accessible for trailered mobile units, such as those with traveling container cranes.

Delivery of Treated Water

This approach also utilizes a mobile unit, but treats ballast water on uptake rather than discharge. The only difference in equipment between this approach and treating on discharge is that a submersible pump is required to pump water from the port basin to the treatment unit.

Advantages of this method include:

- Ballast spillage is harmless.
- Residual slurry can be led directly back into the port basin.
    - No treatment or storage required.

Disadvantages include:

- Complicated permitting issues.
    - Destination port must be assured that discharge of treated water is safe.
- Can only be used for ships on short service routes.
    - Risk of regrowth of zooplankton on long voyages.

Another consideration with this method is that storage tanks could be used to build up a supply of treated water. This allows for more flexibility during higher traffic periods. However, periodic chlorination of the stored water would be necessary to prevent regrowth of zooplankton.

Staffing

The study assumes that treatment operations are taken on by a third party (i.e., not the port authorities or vessel owners) such as stevedoring companies, which already conduct business at port terminals and are intimately familiar with their operations.

With input from stevedoring companies at Esbjerg and Fredericia, the staffing costs in such ports are estimated to be 1,500,000 DKK per year.

Discharge

Based on the applicable regulations, the following considerations are identified for discharge:

- Discharge of treated ballast:
    - To a port basin (“possibly feasible”).
        - From a land-based facility: A discharge permit for treated water must be obtained; this may be difficult since the contents of the water may be unknown. Authorities may grant a permit based on best available technology, however.
        - From a barge-based facility: Because a treatment plant on a barge is considered onboard treatment, treated ballast may be discharged to port basin if handled according to regulations.
    - To a sewage treatment plant (“non-feasible”).
        - Chloride content in seawater is too high for treatment at a sewage plant as it risks corrosion of the piping system.
    - To a waste water treatment plant (“non-feasible”).
        - Likely too expensive to transport the water.
        - Chloride content may also be an issue.
- Discharge of residuals from filtration:
    - To an ordinary landfill (“feasible”).
        - 15% dry matter required; residuals must be on the site’s acceptable discharge list.
    - To a hazardous waste incineration facility (“possibly feasible”).
        - Very expensive.
    - To an incineration facility (“possibly feasible”).
        - 25%-30% dry matter required; chloride content may be an issue.
    - To a waste water treatment plant (“possibly feasible”).
        - Chloride content may be an issue.
    - To a sewer discharging to a public water treatment plant (“non-feasible”).
        - Chloride content is too high.
    - To the sea (“non-feasible”).
        - Illegal to discharge residuals to sea.
    - For use as fertilizer (“non-feasible”).
        - Residuals have no soil-improving properties.

Other Environmental Considerations

The study briefly considers some additional environmental impacts of treatment.

- Noise limits.

- The recommended limit, at night, in mixed industrial and residential areas is 40 dBA. Daytime limits are higher. At 100-meters away, the generator proposed for the treatment unit contributes an estimated 35 dBA. If both primary and reserve treatment units are used, the two generators would contribute roughly 38 dBA, total.

- Air pollution.
  - The emissions from the treatment unit generators is not expected to exceed Danish EPA guidelines.

2.4.2.3 Vessel Modifications

The study identifies that vessels' piping would need to be modified so that ballast could be discharged at least one meter above the quay level when the vessel is in an in-ballast condition. It is noted that the vessels considered typically provide a pressure of 3.0 bar at sea level. This exceeds the required pressure of 1.5 bar to achieve the necessary discharge rate of 300 MT/h. To accommodate various berth arrangements, discharge points should be provided on both sides of the ship and located as near as possible to the stern so as not to interfere with cargo operations.

2.4.3 Economic Viability

2.4.3.1 Capital and Operating Expenses of Mobile Unit

Table 9 summarizes the capital and operating expenses of the mobile treatment unit. These cost estimates form the basis for the financial analysis conducted on the six business cases.

Table 9 Estimated capital expenses and operating expenses (COWI A/S, 2012)

Capital Expenses	
Item	**Cost (DKK)**
Mobile treatment unit	**3,700,000**
Treatment unit	2,400,000
Flatbed trailer	200,000
Set of spare parts, flexible pipe, hoses	150,000
Generator	200,000
Truck unit for transport	750,000
Storage tanks	**500,000**
32-m^3 container tank	50,000
150-m^3 open tank with overflow	300,000
Misc. costs	150,000
Total capital expenses	**4,200,000**
For reserve unit only (no tanks or truck)	2,950,000
Fixed Operating Expenses	
Item	**Cost (DKK/year)**
Stevedore operator's personnel	1,200,000
Administration, management	300,000
Total fixed operating expenses	**1,500,000**

Variable Operating Expenses	
Item	**Cost (DKK/ton)**
Power consumption	0.50
Use of spares and maintenance	0.60
Fuel for truck and maintenance	0.40
Estimated cost of transport of slurry to depot*	0.40
Depot fee	0.20
Total variable operating expenses	**2.10**

*Assumes 5 kg of slurry produced per ton of ballast water

Combining these cost estimates with the characteristics of the six business cases, capital and operating expenses are estimated for each case.

2.4.3.2 Scenario A-1

This scenario considers all three vessel types that regularly visit the Port of Esbjerg:

1. DFDS freight ferries.
2. Sea Cargo freight ferries.
3. Service vessels that visit offshore platforms in the North Sea.

Table 10 Summary of Scenario A-1

Port	Vessel Type	Annual Vol. MT)	Treatment Units	Capex	Opex Fixed)	Opex Variable)
Esbjerg	1 & 2	196,000	1 primary + 1 reserve	7,150,000 DKK	1,500,000 DKK/year	2.10 DKK/MT
	3	104,000				

This business case assumes that the other ports that the vessels call to also have shore-based treatment available, but does not include the cost of the treatment at these other ports in the cost estimate.

2.4.3.3 Scenario A-2

This scenario looks at vessel Types 1 and 3 from Scenario A-1 and examines the cost of treatment at all their ports of call.

Table 11 Summary of Scenario A-2

Port	Vessel Type	Annual Vol. (MT)	Treatment Units	Capex	Opex Fixed	Opex Variable)
Esbjerg	1	136,000	5 primary + 3 reserve	2,985,000 DKK	6,300,000 DKK/year *4x1.2M +1.5M*	2.10 DKK/MT
	3	104,000				
Harwich	1	44,000				
Immingham	1	270,000				
Gothenburg	1	90,000				
Rotterdam	1	315,000				
Felixstowe	1	225,000				

2.4.3.4 Scenario A-3

This scenario is identical to A-1, except that only service ships (Type 3) are considered.

Table 12 Summary of Scenario A-3

Port	Vessel Type	Annual Vol. MT)	Treatment Units	Capex	Opex Fixed)	Opex Variable)
Esbjerg	3	104,000	1 primary	4,200,000 DKK	1,500,000 DKK/year	2.10 DKK/MT

2.4.3.5 Scenario A-4

This scenario looks at barge-based treatment for the same ship types serviced in A-1. Capital expenses considered are purchasing a barge, purchasing a treatment unit, and making necessary modifications to the barge, totaling 21,000,000 DKK.

Operating costs considered are rental cost of the barge, labor, plus administration costs and port fees, and total 4,700,000 DKK, annually. Variable operating costs are estimated at 2.10 DKK/t.

2.4.3.6 Scenario A-5

This scenario supplies treated water to ships for ballast at the port of departure for the same ship types and ports serviced in A-2, but not including the service ships (Type 3) that call to Esbjerg. Notably, no storage tanks are necessary in this scenario, and thus the each of the five primary units is 500,000 DKK less expensive. Moreover, without variable expenses from storing and handling the residual slurry, the variable operating costs are much lower in this scenario.

Table 13 Summary of Scenario A-5

Port	Vessel Type	Annual Vol. (MT)	Treatment Units	Capex	Opex Fixed	Opex Variable)
Esbjerg	1	136,000	5 primary + 3 reserve	27,350,000 DKK	6,300,000 DKK/year *4x1.2M +1.5M*	1.20 DKK/MT
Harwich	1	44,000				
Immingham	1	270,000				
Gothenburg	1	90,000				
Rotterdam	1	315,000				
Felixstowe	1	225,000				

2.4.3.7 Scenario B-1

In this scenario, a mobile treatment unit is used to treat all vessels regularly calling the Port of Fredericia (excluding the large tankers visiting the Shell terminal, which cannot be accessed by the mobile unit). These vessels include container ships, RoRo freight ferries, small tankers, and general cargo vessels, and represent 520 vessel calls per year.

Table 14 Summary of Scenario B-1

Port	Vessel Type	Annual Vol. MT)	Treatment Units	Capex	Opex Fixed)	Opex Variable)
Fredericia	see above)	156,000	1 primary + 1 reserve	7,150,000 DKK	1,500,000 DKK/year	2.10 DKK/MT

2.4.3.8 Shipboard Treatment

For comparison with the shore-based scenarios, capital and operating expenses are estimated for the shipboard treatment, serving the same vessels as in A-2. For the estimates, the following assumptions are made:

- Cost of units installed on ships: 3,000,000 DKK per ship.
- There are no fixed operating costs since crew members would be expected to carry out tasks associated with treatment as part of normal duties.
- Variable operating costs are equal to that of shore-based operations, minus the cost of treating and handling the residual material.
- Opportunity costs for space on the ship used by the treatment system are not considered.

There are 18 total vessels considered in A-2, and thus the capital costs include 18 treatment units, totaling 54,000,000 DKK. Variable operating costs include treating a total of 1,184,000 MT of ballast water from these vessels at a rate of 1.20 DKK per ton. Thus, variable operating costs total 1,342,000 DKK, annually.

2.4.4 Results

Based on the baseline capital and operating expenses summarized in the previous section, the study conducts a financial analysis to determine the cost per ton of ballast water treated for each of the six business cases as well as the case of shipboard treatment.

The basic assumptions of the financial analysis are:

- Interest rate: 6.5%
- Return on equity: 15%
- Depreciation: 15 years
- Operating period: 15 years
- Tenor on debt: 10 years
- Debt financed: 80%
- Equity financed: 20%

The following table summarizes the results of the analysis.

Table 15 Summary of financial analysis (COWI A/S, 2012)

Scenario	Annual Vol. (MT)	MT/Call	DKK/MT	DKK/Call
A-1	300,000	300	10.38	3,115
A-2	1,184,000	300	10.28	3,084
A-3	104,000	200	22.09	4,418
A-4	300,000	300	27.55	8,264
A-5	108,000	300	10.52	3,157
B-1	156,000	300	18.03	5,409
Shipboard	1,184,000	300	7.48	2,244

To determine the most feasible scenario, the study compares the cost and operational factors of each business case. Scenario A-4, barge-based treatment, is the least cost-effective due to the high capital costs incurred for barge purchase and modification. Scenario A-3 suffers from low turnover and volume of ballast water treated.

Scenarios A-1, A-2, and A-5 have nearly identical treatment costs per call and offer the most cost-effective shore-based treatment approaches. As they cannot be easily differentiated by price, operational considerations determine the most feasible approach. The major assumption for A-1 is that all other ports where the vessels of interest call also have shore-based treatment available. However, most of those other ports receive much less vessel traffic than Esbjerg, and thus may not be able to feasibly implement a shore-based treatment approach. Therefore, the authors note, it is unlikely that this assumption is a realistic one. A-2 and A-5 both consider the costs of operating mobile units at every port of call for a particular fleet of vessels (five primary units and three reserve units for each scenario). The two methods are differentiated in that A-2 treats ballast at discharge and A-5 on uptake. Though treating on uptake reduces capital and operating expenses (as storage tanks are not necessary), it restricts the number of vessel service routes that can be served. During longer voyages, zooplankton may regrow to higher than acceptable concentrations, and thus only short service routes are viable for this scenario. From both a cost and operational standpoint, then, A-2 is the most feasible scenario for shore-based treatment in this study. Though the study finds Scenario A-2 to be roughly 40% more expensive than the estimated cost per call of shipboard treatment, it is noted that the cost differential is small enough that the shore-based treatment approach considered warrants further investigation. The study concludes that shore-based treatment may be a viable approach for vessel fleets on dedicated service routes and with sufficient quantities of ballast water for treatment.

2.5 King (2013)

King et al.'s "Economic and Logistic Feasibility of Port-based Ballast Water Treatment," examines a particular case study for barge-based contingency treatment at the Port of Baltimore. The study assumes that shipboard ballast water treatment will continue to be the focus of the market, but that shore-based treatment could provide a contingency option for ships that either cannot install a shipboard treatment before regulations enter into force or have existing shipboard units that cannot meet compliance standards (due to malfunction or otherwise).

The study determines that a barge-based treatment approach is likely not feasible at the Port of Baltimore due to operational challenges such as large distances between terminals at the port.

2.5.1 Background

This study of the Port of Baltimore examines shore-based treatment as a contingency option. The economic viability of contingency treatment relies on the prospect that a significant number of ships will arrive to port without an adequate treatment approach and, facing noncompliance charges, will opt to pay to use shore-based contingency treatment. Ships may be legally prohibited from discharging ballast water directly and choose to use a port-based treatment for the following reasons:

- BWTS malfunctions.
- Unproven BWTS maintenance and repair protocols.
- BWTS supply and installation bottlenecks.

The study notes that it is difficult to account for all of the reasons why a contingency measure would need to be used. Thus, anticipating the demand for contingency treatment is quite challenging.

According to data collected from National Ballast Information Clearinghouse (NBIC), 282 overseas and 189 coastwise vessels discharged ballast water at the Port of Baltimore in 2011. For this analysis, it is estimated that 20% of these vessels would need to use a contingency treatment option. Only overseas vessels are considered in this study. The NBIC defines an "overseas" vessel as a ship that voyages to a US port immediately after passage outside the U.S. or Canadian exclusive economic zone (see NBIC, 2015). If 20% of overseas vessels calling the port require contingency treatment, this would result in roughly 50-60 treatment events, annually.

Table 16 summarizes the types of ships and their discharges at the Port of Baltimore in 2011.

Table 16 Summary of coastwise and overseas vessel calls and ballast discharges (King, 2013)

Ship Type	No. of Overseas Ships Discharging	Total Discharge Volume (MT)	No. of Coastwise Ships Discharging	Total Discharge Volume (MT)
Bulker	198	7,743,081	46	736,887
Combo	1	1,906	-	-
Container	27	60,130	23	20,483
General Cargo	28	46,377	10	25,268
Passenger	6	3,692	49	40,427
RoRo	16	16,924	6	2,802
Tanker	6	4,580	17	263,373
Other	-	-	38	121,696
Total	**282**	**7,876,690**	**189**	**1,210,936**

Bulkers are the primary focus of the study, as they account for the largest volume of ballast discharge at the Port of Baltimore. The general layout and ship traffic at the port is in Figure 7.

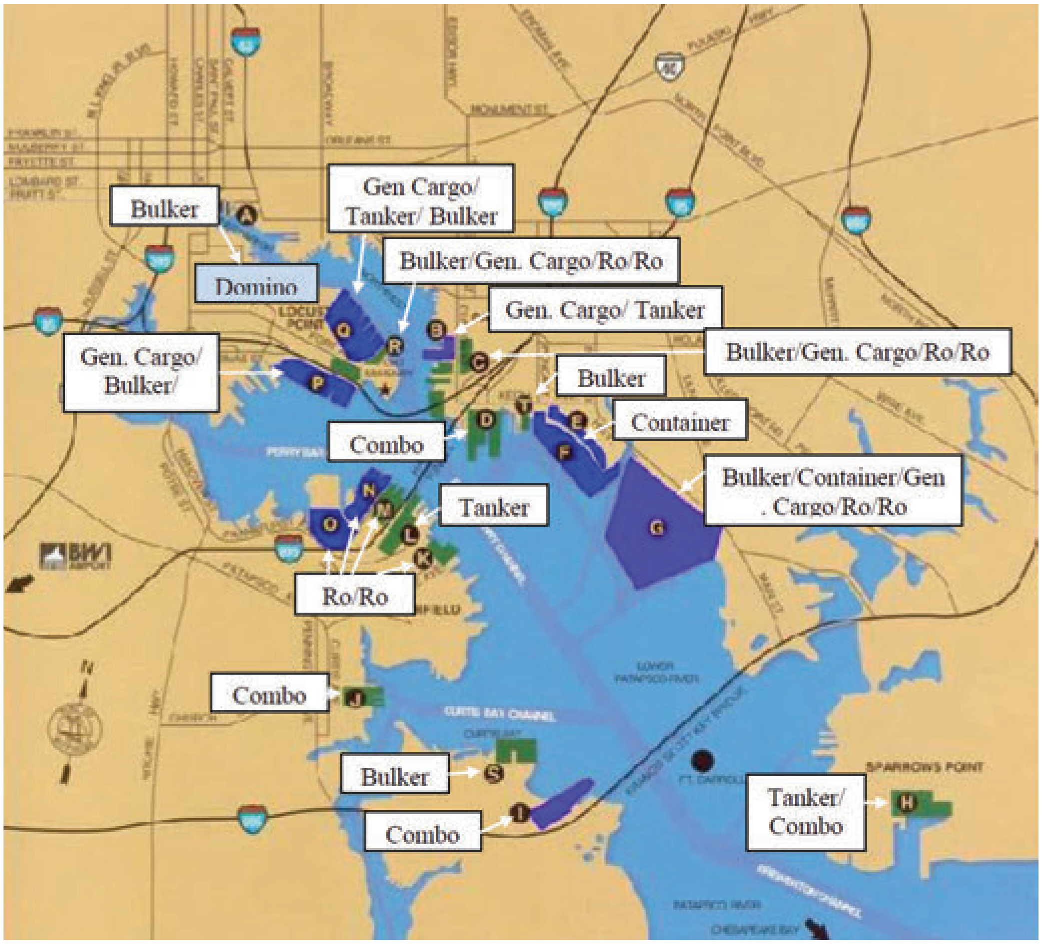

Figure 7 Major terminals and type of ship traffic at the Port of Baltimore (King, 2013).

2.5.2 Methods

The study estimates the capital costs and operating expenses for a barge-based treatment approach at the Port of Baltimore. These estimates, along with other logistical considerations, determine the feasibility of the case study. Aside from the available literature on ballast water treatment, the study draws upon four main sources of information:

- Due diligence performed by the University of Maryland Maritime Environmental Research Center (MERC) before construction of the MERC barge-based BWTS testing facility.
- Several years of cost data related to the operation of the MERC barge-based BWTS testing facility.
- Interviews with port managers, shipping companies, and commercial fuel barge operators about logistical issues, particularly at the Port of Baltimore.
- Records of ship calls and ballast water discharges at the port.

The study considers both supply-side (feasibility of constructing a barge-based treatment facility) and demand-side issues (number of ships and total ballast water to be treated; how much users of the facility would be willing to pay for treatment).

Authors note that, while capital and operating costs developed in the study are "fairly reliable," and would likely be similar for many other ports, the estimates for ship demand are inherently difficult to determine for contingency treatment. Such estimates are likely to vary from port to port, and relevant factors are still in flux due to the changing regulatory climate and uncertain market conditions.

2.5.2.1 Treatment Approach

The treatment technology considered is a filtration/UV disinfection unit with a treatment rate of 10,000 MT/h. Two such units would be mounted on a 240-ft by 60-ft barge, and thus the total treatment capacity is 20,000 MT/h. The barge would be able to accept, treat, and discharge ballast water at a high enough rate so that no significant storage capacity is required.

2.5.2.2 Port Logistics

The study considers several logistical issues of a barge-based approach at the Port of Baltimore.

- No certainty that barge-based treatment will be more reliable than shipboard.
    - Though the barge-based approach is a contingency measure in case of shipboard failure, the treatment unit used on the barge will likely be similar to that used for a shipboard approach and may thus experience similar maintenance issues. For redundancy, multiple treatment barges may be needed, which would drastically increase costs.
- Bulkers call at a variety of terminals that are spread out geographically around the port.
    - The vast majority of ballast water discharge at the port is from bulkers, and, as shown in Figure 7, these vessels call at several terminals scattered throughout the port. This factor makes it difficult to identify a viable location for the barge that provides convenient access to all the relevant terminals. Transport time and resulting delays need to be considered.
- Vessels may need to discharge ballast before reaching the port.
    - Though the study does not investigate whether or not ships' visiting the Port of Baltimore discharge ballast before reaching port, it is noted that such a practice could pose difficulties to a barge-based approach.
- Multiple ships arriving per day may cause bottleneck issues and result in costly delays.
    - The study analyzed vessel traffic at the port and identified that, in 2011, there were at least 42 days in which two or more vessels discharged ballast water at the port. It is noted that, if 20% of those ~84 ships required contingency treatment, a bottleneck could occur on a maximum of 16 days per year. Hedging against this situation would involve purchasing additional treatment barges, which would likely sit idle for the majority of the year.

2.5.2.3 Vessel Modifications

The study does not develop detailed estimates of the cost to modify vessels to connect with a barge-based treatment facility; however, the study updates estimates from Glosten (2002) to 2012 dollars and arrives at the following average cost per ship:

- Tanker: $2,433,000
- Grain ship: $137,000
- Break-bulk: $390,000
- RoRo: $207,000

Further investigation would be necessary to determine the costs for bulkers visiting the Port of Baltimore. Notably, because the treatment approach in consideration is a contingency measure, all modification costs to use the system are costs that the ship owner must pay in addition to installing an onboard treatment unit.

2.5.3 Economic Viability

2.5.3.1 Revenues

Revenue estimates for contingency treatment services are based on the following assumptions:

- Contingency treatment demand: 50 vessels per year.
    - Roughly 20% of annual bulker traffic to the port.
- Vessels would be willing to pay $25,000-$50,000 for contingency treatment.

These assumptions yield estimated annual gross revenues of $1.25-2.5 million.

2.5.3.2 Fixed Costs

Annual fixed costs are summarized below.

Table 17 Summary of annual fixed costs in King (2013)

Debt payments on barge purchase ($1.8 million over 20 years at 5% interest)	$144,000
Debt payments on purchase and installation of two treatment unit ($2.1 million over 20 years at 5% interest)	$168,500
Barge maintenance costs	$10,000
Salary for one full-time manager direct and indirect costs)	$100,000
Salaries for two full-time employees to maintain and operate barge direct and indirect costs)	$160,000
Barge docking costs	$6,000
Total	**$588,500 per year**

Average, per unit costs are estimated to be four cents per MT of ballast water treated. Assuming cargo loading operations of 10 hours per ship and discharge of 70,000 MT per ship, treatment cost is estimated to be $2,800 per treatment. This does not include cost for tug operations, which is estimated at $3,000 per treatment. Total estimated cost is thus $6,600 per treatment, or $330,000 annually for 50 treatments per year.

Considering the above estimates, total annual fixed and variable costs amount to $918,500.

2.5.4 Results

The study concludes that, to break even, 22 vessels per year would need to receive treatment at a cost of $50,000 per treatment. Though this may be financially feasible, it is emphasized that logistical considerations may prevent the implementation of a barge-based contingency treatment approach at the Port of Baltimore. For vessels to invest in the appropriate modifications, such an approach would need to be implemented at other ports as well. However, if those ports receive less traffic than the Port of Baltimore, investing in a contingency approach may be financially impractical. Additionally, the study notes that ship owners must consider the additional costs of vessel modifications and the potential of incurring delays when opting to use contingency treatment. The study determines that, collectively, these factors make the economic feasibility of a barge-based contingency approach highly unlikely at the Port of Baltimore.

2.6 Ballast Water Treatment Boat (2013)

At the 65th session of the IMO Marine Environment Protection Committee, India submitted MEPC 65/2/20, "Ballast Water Treatment Boat (BWTBoat)–a viable alternative for effective and faster implementation of the BWM convention." Authors were asked to clarify some of the concepts presented in this paper, and two additional submissions were provided for the 66th session of the MEPC. MEPC 66/2/8 focuses on the regulatory aspects of the BWTBoat treatment concept, while MEPC 66/INF.17 provides a detailed look at the concept and offers substantial data analysis to demonstrate its economic viability. MEPC 66/INF.17 is summarized herein, as it is the most comprehensive study on the BWTBoat concept.

The submitting group (India) carried out the analysis in this study jointly with the World Maritime University (WMU) in Malmö, Sweden. The study assesses the viability of the BWTBoat concept by examining the vessels calls in two large shipping regions, and determining how many BWTBoats would be required to service each region compared to the number of shipboard systems that would need to be installed.

Ultimately, it is determined that significantly less BWTBoats would be required, and the study asserts that this method would reduce the environmental footprint of ballast water treatment, as well as the overall economic burden on the industry.

This study refers to some specifics of the IMO International Convention on the Management of Ships' Ballast Water and Sediments (AKA "the Convention"). For a detailed review of the Convention, refer to Gollasch (2007).

2.6.1 Background

The intent of the study is to suggest that the MEPC to consider the approval of the BWTBoat concept as an "other method" of ballast water management under Regulation B-3.7 of the Convention. Authors assert that the BWTBoat alternative is a "united shared green approach" that adheres to the IMO objective of sustainable development, reducing environmental impact and the overall financial burden of ballast water treatment. To demonstrate this, the study analyzes shipping data from two major shipping regions to determine the reduction in total treatment systems under a BWM regime that entirely replaces shipboard systems with regional fleets of BWTBoats. The two shipping regions considered are:

- **Region 1**: Persian Gulf, Red Sea, East Africa, Asia, and Oceania.
- **Region 2**: United Kingdom, Baltic Sea, North Sea, Mediterranean Sea, and Black Sea.

Figure 8   Map of Region 1 (BWTBoat, 2013

Figure 9   Map of Region 2 (BWTBoat, 2013

Region 1 is selected due to the large quantity of exports within the region, including oil exports from the Persian Gulf to various Asian countries and coal and iron exports from the Oceania region. Moreover, there are several existing memoranda of understanding (MOUs) between the countries in this region; a similar agreement would be advantageous for the implementation of a region-wide BWTBoat fleet.

Region 2 is selected due to the region's numerous oil loading terminals in the Mediterranean Sea. Additionally, many of the countries in this region are part of the European Union, and thus an agreed upon regional BWM fleet could be facilitated through EU legislation.

The two regions account for a very large percentage of international shipping trade: 48.4% and 29.6% for Regions 1 and 2, respectively.

2.6.2 Methods

To estimate the total number of BWTBoats required to a serve a region, the study follows two general steps:

- Indicative analysis (Region 1 and Region 2)
    - "Indicative" analysis entails, in this study, the analysis of the routes of 13,000 ships in Region 1 and 12,000 ships in Region 2 over a twelve-month period to determine the number of ships in each region that call exclusively to regional ports.
    - Only vessels with flag-states located within their respective regions are considered in indicative analysis.
- Detailed analysis (Region 1, only)
    - To more accurately determine how many ships operate regionally, "detailed" analysis entails using the IHS Fairplay database to examine vessel routes over a five- to six-year period.
    - Rather than analyzing all 13,000 ships, a sampling technique is employed that covers a representative range of ship types, deadweight tonnages, and dates of construction.
    - The analysis aims to:
        - Ensure regional trading pattern of ships.
        - Determine the number of ports where the representative ships called.
        - Determine the most frequently visited ports by representative ships and, in turn, the number of BWTBoats required at each port.

Additionally, the study offers significant detail on the BWTBoat concept. This includes design parameters and possible modes of implementation, as described in the following sections.

2.6.2.1 Treatment Approach

The BWTBoat is a marine vessel-based ballast water treatment approach. The BWTBoat concept specifies the use of a self-propelled marine vessel. The design proposes either a UV or a chlorination treatment technology be installed on the vessel for treatment. Figure 10 and Figure 11 show the general ballasting and deballasting process envisioned for the BWTBoat.

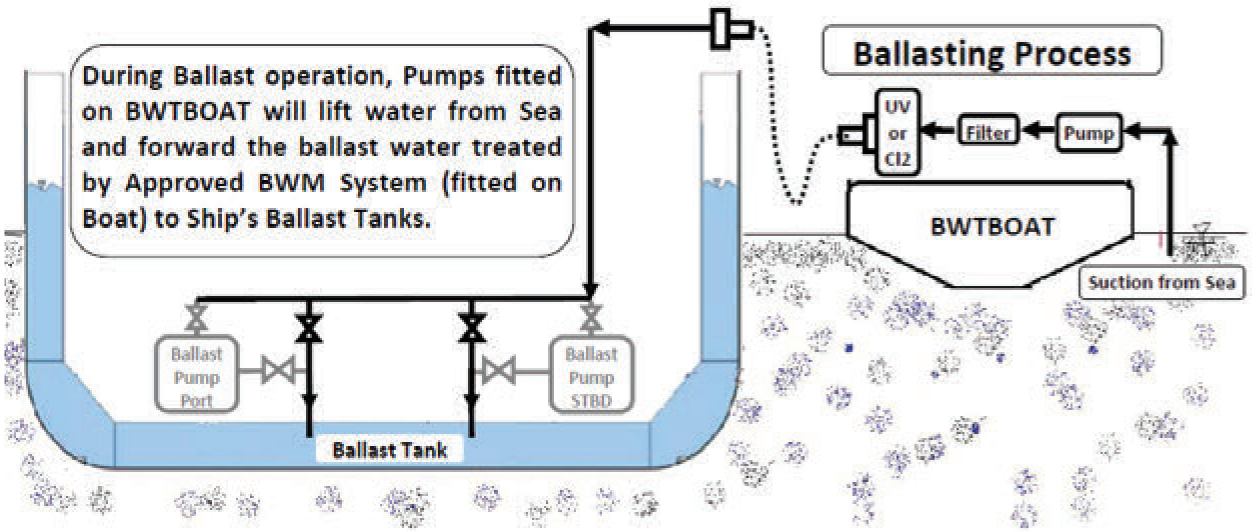

Figure 10 Illustration of the BWTBoat ballasting process (BWTBoat, 2013)

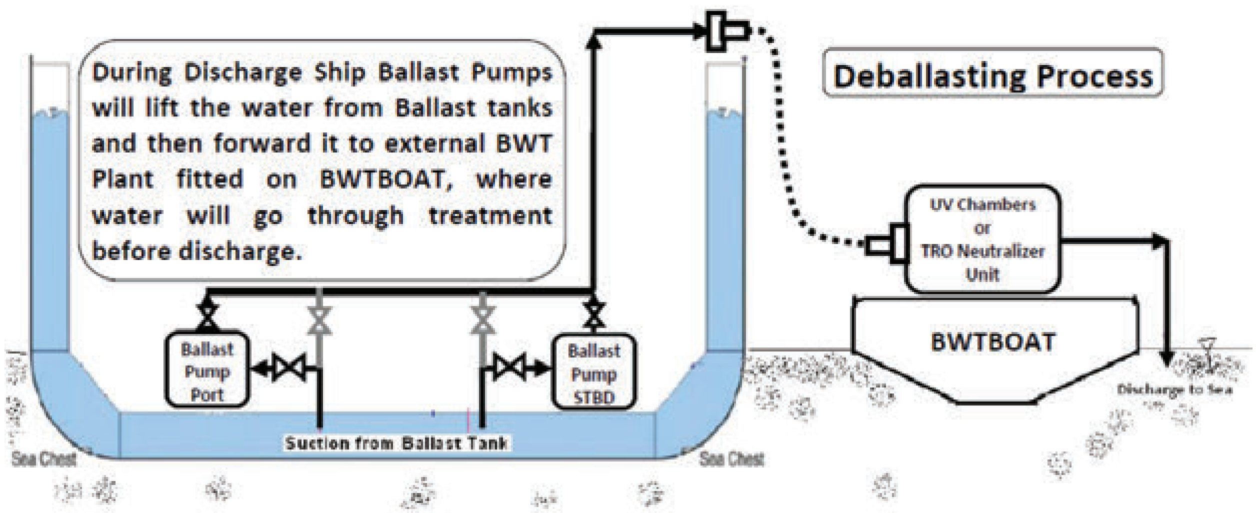

Figure 11 Illustration of the BWTBoat deballasting process (BWTBoat, 2013)

The study specifies the following components in the BWTBoat's design:

- Diesel generator set for powering the BWTS, propulsion system, and pumps.
- Azimuthing thrusters.
- Modular, customized, type-approved BWTS on the BWTBoat's deck.
- Stores space containing flexible pipes with universal connections and accessories.
- Ballast water sample collection points.
- Network of piping, hoses, and valves.
- Control room that includes the navigation system, control panel for the BWTS, diesel generator set panel, and mimic panel with display for piping and valves.
- Tankage for fuel, test water, sample water, untreated water, etc.
- Crew rest room.

Based on capacity needs, several treatment units can be added to the boat to increase the treatment rate. The general arrangement for the BWTBoat is shown in Figure 12.

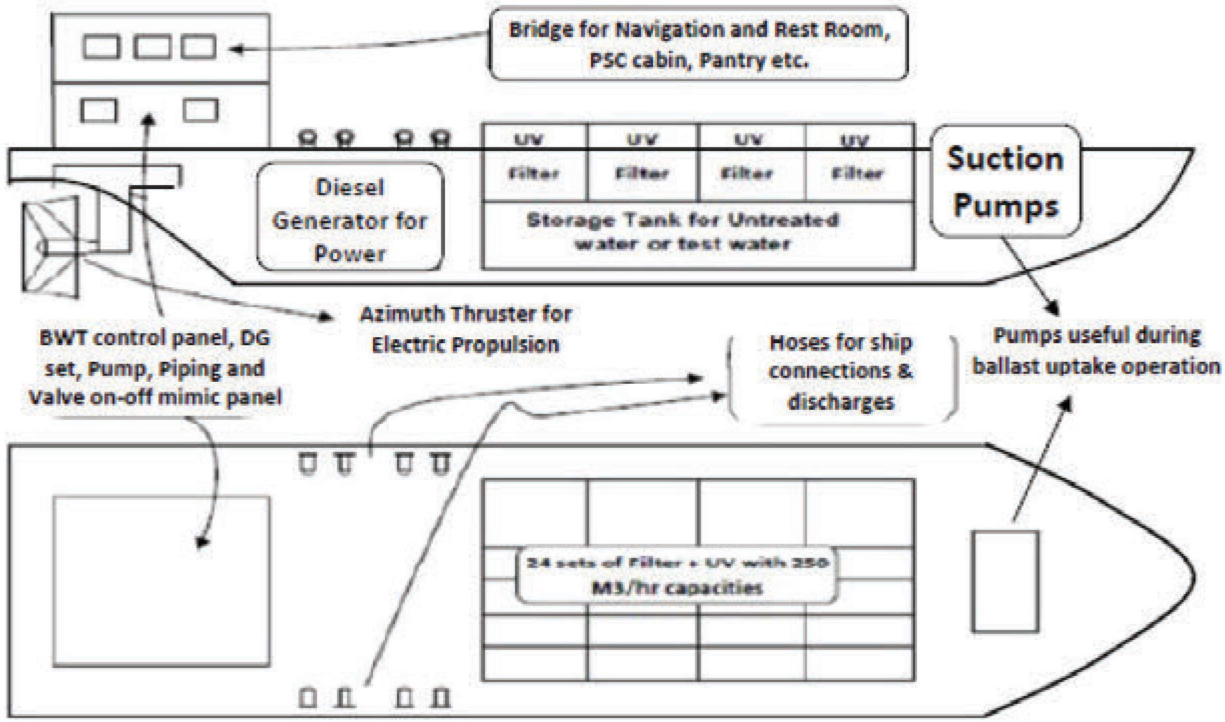

Figure 12 General arrangement of BWTBoat (BWTBoat, 2013)

2.6.2.2 Port Logistics

The study proposes that a BWTBoat be used at both uptake and discharge of ballast water due to the following characteristics of the treatment technologies considered:

- UV Disinfection
    - Though disinfection occurs nearly instantaneously with this method, organism regrowth is possible during the longer voyage.
- Chlorination
    - Chlorination typically prevents organism regrowth for at least six hours; however, Guideline G9 of the Convention will require that less than 0.2 mg/liter of total residual oxidants (TRO) be present in the discharged ballast water (chloride oxidants, in this case). Thus, a neutralizing agent will need to be added before discharge.

Based on the above considerations, the four BWTBoat implementation options are outlined as follows:

1. Filtration boat at the ballasting site; UV boat at the deballasting site.

    a. Filtration boat removes sediments and organisms greater than 50 µm on uptake, yielding clear ballast water ideal for UV treatment. UV treatment boat disinfects water to applicable standards before discharging to sea.

    b. Study asserts that this option is ideal for oil tankers, coal carriers, iron ore carriers, grain carriers, LNG-LPG carriers, and other dry bulk ships because of their long voyages and generally fixed routes.

    c. It is cautioned that this method has not been properly tested. Typically, UV systems are tested by treating at both uptake and discharge.

2. Filtration + UV boat at the ballasting site; filtration + UV boat at the deballasting site.

    a. Container liners, general cargo ships, and car carriers, which may have simultaneous cargo loading and unloading operations, short port stays, and short voyage times, benefit from the fast treatment time of UV disinfection.

    b. Positioning a UV-capable boat at both arrival and departure ports accounts for the variability of the vessels' cargo operations (i.e., ballast discharge may occur at either port, depending on the cargo operation).

    c. Similar to Option 1, filtration only occurs on uptake.

3. Filtration + chlorination boat at the ballasting site; TRO neutralizer boat at the deballasting site.

    a. Filtration + chlorination (via direct dosage or electrolysis) boat removes sediment and doses ballast water with chlorine such that all microorganisms are killed within 12 hours with minimum residual oxidant. Prior to discharge, a boat equipped with TRO neutralizer, such as sodium sulphite, bisulphate, or thiosulphate, neutralizes the ballast water.

    b. Study notes that UV disinfection may also be employed at discharge, if necessary.

    c. This option is suitable for the same ship types as Option 1.

    d. Study notes that this option is already proven to be effective, and could be implemented immediately.

4. Filtration + chlorination + UV + TRO neutralizer boats for use at minor ports.

    a. A BWTBoat with all of the considered technologies could be used at minor ports to provide flexibility for serving a variety of ships.

Sediment control

The study notes that the BWTBoat can address regulations on sediment in two ways:

- Filtration at ballast uptake allows sediment to be deposited at the source.
- BWTBoats could also be used as sediment reception facilities if ships need to clean their ballast tanks in port.

BWTBoats for Contingency Treatment

Though the focus of the study is on BWTBoats as a primary treatment method for shipping regions, it is noted that a BWTBoat could be used as a contingency measure in case of ships entering port with untreated ballast (due to shipboard system malfunction or otherwise). The authors note that the BWTBoat could be equipped with any of the various technologies discussed during the second expert workshop on port-based contingency measures (IMO GIA, 2013); these include UV disinfection and chemical-based treatment such as chlorination or other traditional methods such as brine or salt addition.

2.6.2.3 Vessel Modifications

The study notes that ships' piping and pumping systems would need to be modified to divert ballast water up to a location on deck. The system should be able to connect with the BWTBoat via a universal flange connection; in particular, the standard could conform to OCIMF (Oil Companies International Marine Forum standards.

2.6.3 Economic Viability

The study considers economic viability to be determined by whether or not the total investment required to implement a fleet of BWTBoats in a region is less than the total investment to fit all of the vessels in that region with a shipboard treatment system. To do this, the study estimates both the number of regional ships operating within the two regions of interest and the number of BWTBoats that would be required to serve all of ports in the region (see Section 2.6.4).

Additionally, authors acknowledged that the service fee for use of BWTBoats should be selected to account for the BWTBoat crew salary and sufficient return on investment for the treatment unit, boat cost, and operational expenses.

2.6.3.1 Financing Options

Consideration is given to how BWTBoats might be financed to facilitate implementation. The point is made that, though comparison is often drawn between shore-based treatment facilities and oily water/garbage reception facilities, the major difference is that if a shore-based solution were established for a particular region, it would see much more frequent use than the oily water/garbage reception facilities. This suggests that port-based facilities could be a successful business model – more similar to that of tugs and bunker services – and thus it may be feasible to attract investors.

Furthermore, a port-based ballast water solution implementing a "per use" fee would have consistent revenues (assuming the port receives dedicated vessel calls from ships without onboard treatment approaches). Such an operation would be appealing to banks, which may prefer to invest in ventures with reliable revenue sources.

2.6.4 Results

2.6.4.1 Region 1

Indicative analysis of for Regional 1 yielded the percentage of ships flagged by regional countries that called exclusively to ports within Region 1 over a twelve-month period.

Table 18 Percent of Region 1 flagged vessels operating regionally in a 12-month period (BWTBOAT 2013)

DWT:	0 – 3K*	3 – 5K	5 – 10K	10 – 20K	20 – 50K	50 – 100K	>100K	Total
All Vessels	13,160	2,274	2,399	1,552	2,642	2,779	1,355	26,161
Regional Vessels	13,160	1,185	1,955	838	828	611	214	19,491
Percent Regional	**100%**	**83%**	**81%**	**54%**	**31%**	**22%**	**16%**	**75%**

*Only includes vessels above 400 gross tons, per IMO Convention. All vessels in this category are assumed to operate regionally, and thus are not actually examined in the analysis.

The study notes that the percentage of regional vessels is inversely related to the DWT range.

Detailed analysis for Region 1 examines the same vessel types, but over a five- to six-year period to determine the percentage of regional vessels with greater confidence. Rather than examining each vessel over this period (as looking at six years of data for each of the ~13,000 vessels greater than 3,000 DWT would be prohibitively time-intensive), subsets of each vessel category are considered and percentages are calculated accordingly. The study provides examples of this procedure for three countries (India, Singapore, and Japan) to illustrate the procedure. Table 19 is a reproduction of the example provided for India.

Table 19 Example of detailed analysis for India (BWTBoat, 2013

DWT Range	Total Count	Sample Ships Examined	Regional Ships	%	Effective Count
3K-5K	57	15	15	100	57
5K-10K	32	4	3	75	24
10K-20K	18	5	3	60	11
20K-50K	41	32	12	38	15
50K-100K	29	25	13	52	15
100K above	15	13	4	30	4
Total	**192**	**94**	**50**		**126**
Plus the < 3K but > 400DWT ships, of which 100% are assumed regional					609
				Grand Total	**735**

This process is carried out for vessels flagged under each country in Region 1. The detailed analysis determines that 18,445 ships operating in Region 1 are regional (roughly 70%).

After determining the number of regional vessels in Region 1, the study analyzes the number of ports visited and the frequency of visits from these vessels. The frequency of regional vessels visiting a particular port determines the number of BWTBoats needed for each port. The same IHS Fairplay data, which spans five to six years of vessel voyages, is used for this determination. Only a specific sample of ports are examined, and the results from these ports are used to determine the total BWTBoat requirement for Region 1.

The study develops a logic for how many BWTBoats need to be implemented, which is dependent on the vessel traffic at a given port. To obtain a conservative estimate, the study examines periods of maximum vessel traffic for each port, and determines how many BWTBoats are needed to treat all ships without delay during this period. Figure 13 is a visual representation of how the number of BWTBoats is determined for a particular port.

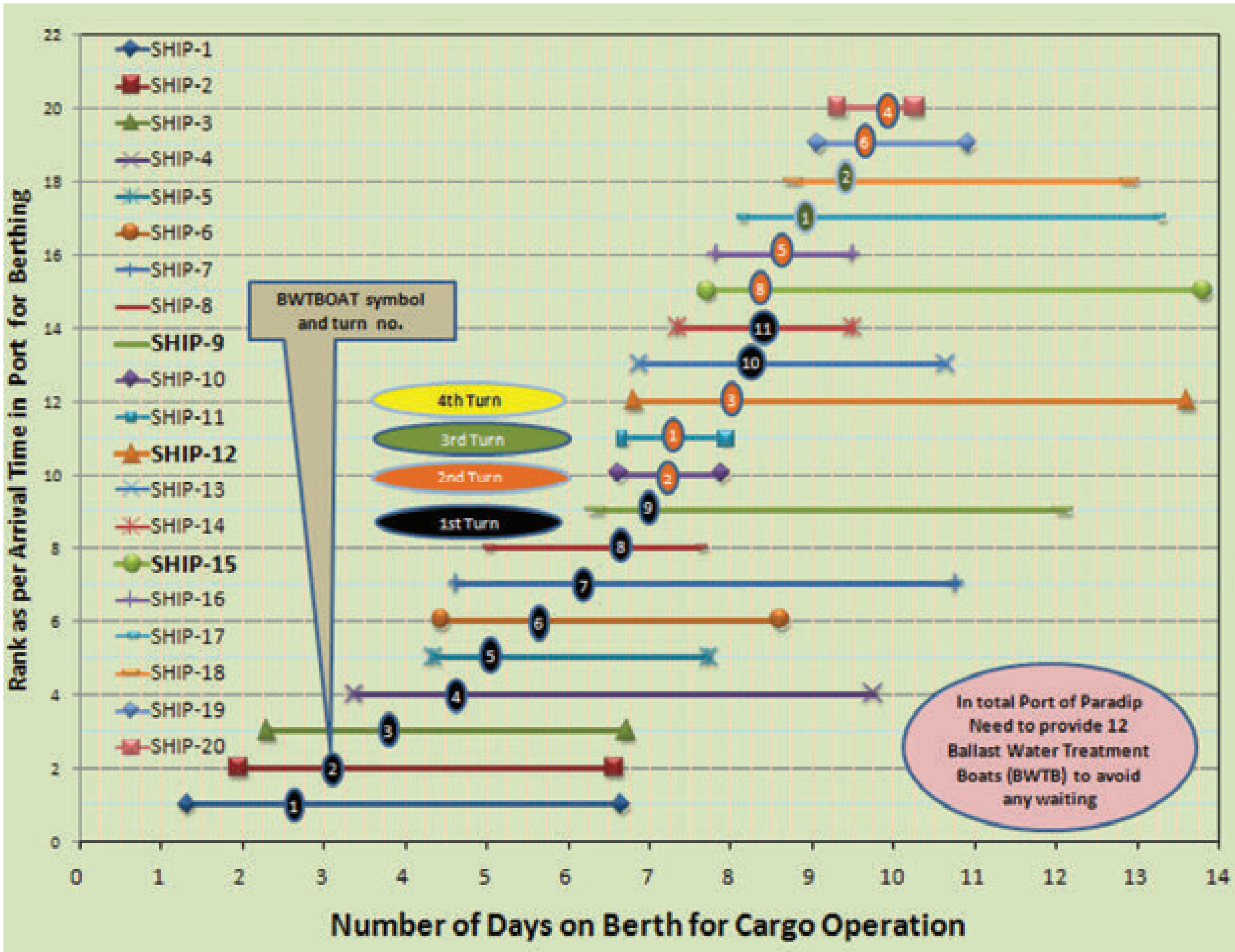

Figure 13 Estimate of the number of BWTBoats required at the Port of Paradip, India (BWTBoat, 2013)

The study notes, however, that cargo operations do not necessarily take place over the entirety of the ship stay, and thus it considers the average length of cargo operations for various ranges of vessel DWT when determining the number of BWTBoats required. Table 20 illustrates another example for the Port of Busan, Korea.

Table 20 Estimate of the number of BWTBoats required at the Port of Busan (BWTBoat, 2013)

<table>
<tr><td colspan="7">Departures from Port of Busan for all DWT vessels on 3 November 2013 (date of maximum departures) with following lengths of port stay:</td></tr>
<tr><td>< 2 h</td><td>2-5 h</td><td>6-10 h</td><td>11-15 h</td><td>16-20 h</td><td>21-30 h</td><td>> 30 h</td></tr>
<tr><td>2</td><td>6</td><td>20</td><td>11</td><td>15</td><td>12</td><td>5</td></tr>
<tr><td colspan="2">2 BWTBoats</td><td>7 BWTBoats</td><td>6 BWTBoats</td><td colspan="3">Total 32 BWTBoats</td></tr>
<tr><td colspan="2">This port stay is only important for ships below 5,000 MT.</td><td>One boat can serve three ships a day with average 8 h per ship.</td><td>One boat can serve two ships a day with average 12 h per ship.</td><td colspan="3">Assuming 24 h as the effective time of cargo operations for each ship, 32 BWTBoats will serve 32 ships in on availability and requirement basis.</td></tr>
<tr><td colspan="7">Thus, for Port of Busan, 47 BWTBoats are required.</td></tr>
</table>

Ultimately, the study determines that approximately 2,400 BWTBoats could serve the regional vessels in Region 1. This result is compared to the number of shipboard treatment units required, which is equal to the number of regional vessels estimated in the indicative analysis: 18,445.

2.6.4.2 Region 2

The study performs only indicative analysis for Region 2, and estimates the number of regional vessels to be 15,770.

2.6.4.3 Suggested Implementation Process

A process is outlined to offer guidance on how a regional BWTBoat network might be implemented, summarized as follows:

1. Member States of specific regions sign a MOU on the deployment of BWTBoats.
2. Member States decide on the number and location of BWTBoats to be implemented, based on a similar analysis to what is presented in this study.
3. MOU publishes the name of the ports and ships which can be brought under this “Other Method” of ballast water management.
4. Technology, treatment capacities, and other details of BWTBoats are decided with IMO guidance.
5. Ports invite BWTS manufacturers to demonstrate their technology and to prove their regulatory compliance. Ports and ship owner associations decide which technologies to implement, possibly with a customized design specific to BWTBoats.
6. Port authorities issue tender for the prescribed number of BWTBoats with the chosen technology and configuration.
7. Either local ship owners, international ship owners, or possibly the ports themselves provide investment.
8. BWTBoats are deployed according to MEPC-established guidelines.
9. Once ships are approved to use BWTBoats, vessel owners must invest in the necessary vessel modifications to utilize the boats.
10. BWTBoats enter into service and charge a fee to reclaim investment and operating costs.

Section 3 Discussion of Key Themes

The key themes for shore-based ballast water treatment and reception are:

- Shore-based reception and treatment approaches.
- Port logistics of implementing shore-based treatment.
- Vessel modifications required for ships to transfer ballast to shore-based facilities.

This section digests the six feasibility reviews from Section 2 and approximately thirty additional literature sources that are listed in Section 5 into these three themes, offering a critical analysis of the existing literature as it applies to the state of California. Though only a few of these literature sources investigate shore-based treatment in detail, all either contribute to or reiterate the current viewpoints on shore-based ballast water treatment presented in the following discussion.

Two large format tables are provided to aid comparison of the literature. The port, vessel, and treatment system characteristics of the six feasibility studies are compared in Table 21. The cost estimates from Brown and Caldwell (2008), COWI (2012), and King (2013) are summarized in Table 22.

3.1 Reception and Treatment Approaches

Reception and treatment includes *any combination of receiving, holding, or processing of ballast water* that supports the objective of ensuring that no ballast water is discharged that does not meet water quality standards. In some approaches, such as COWI (2012), King (2013), and BWTBoat (2013), the ballast water might be immediately treated and require no holding of the ballast water. In other approaches, such as Brown and Caldwell (2008), the ballast water might be held in storage for later transfer to another location for processing – or simply shifted back to another marine vessel, as in RCAC (2005).

The reviewed literature considers the following shore-based reception and treatment approaches:

- New land-based facilities.
- Existing waste water treatment plants.
- Reception and holding for reuse.
- Mobile facilities, inclusive of marine vessels and trucks or other vehicles.

This section provides an overview of each and the relative extent to which each approach has been studied. In addition, a review of the ballast water handling issues relative to each of these methods is provided.

3.1.1 New Land-Based Facilities

The land-based reception facility approach considers *new fixed infrastructure* that has the primary purpose of treating ballast water.

Brown and Caldwell (2007) considers a land-based facility in Phase 1 of their feasibility study. That phase examined how ballast water might be captured, transported, stored, treated, and discharged at such a facility. In the examination, however, the study determines that a tank barge could more practically be used to store and treat ballast water, eliminating the need to transport the ballast water to land. For this reason, Phase 2 of the study (Brown and Caldwell, 2008) does not consider a land-based facility.

Hilliard (2010) asserts that a land-based reception facility could provide a cost-effective ballast water management solution for Caspian Region shipping. However, the study does not go into detail on the facility itself. A suggested treatment rate and storage capacity are provided, but no unique characteristics are identified that would distinguish the proposed land-based facility from other shore-based treatment approaches.

COWI (2012) discusses the development of new land-based treatment facilities. It identifies this as "possibly feasible," noting that obtaining a permit at these European locations may be difficult "as the content of pollutants is unknown."

Literature findings relevant to California include:

- Land-based facilities require transport of the ballast water from the marine vessels to the new facility. The cost, required permits, and potential impact on port operations must be considered. Some of these costs could be offset by currently existing infrastructure, such as pipelines and rail tracks.
- Temporary storage, when combined with a treatment plant, may be an effective option to reduce the size of the treatment plant by accepting potential surges of ballast water discharges. The treatment plant could then continue to process the collected ballast water after the marine vessel has completed its discharge.
- Once the ballast water is collected by a land-based facility, it may no longer be considered ballast water and different effluent restrictions might be applicable. This applies to not only the treated ballast water, but also any filtrate from the process.

3.1.2 Existing Waste Water Treatment Plants

The waste water treatment plant approach considers the use of *existing land-based facilities* for the storage and treatment of offloaded ballast water. This approach seeks to take advantage of the land and facilities that already exist for processing sewage, storm water, and other effluents, and considers using those facilities either as-is or with modifications.

Brown and Caldwell (2007) reviewed the use of an existing nearby treatment plant. They found that the treatment plant did not have adequate capacity during certain times of the year, and as such could only be a part-time solution. The study indicated a need for pre-treatment filtration, but did not include an assessment of the possible efficacy of the existing plant on ballast water discharges. The concept of using the existing treatment plant was not further investigated in their Phase 2 study.

COWI (2012) reviewed the use of existing sewage and waste water treatment plants and found these options non-feasible. The ballast water chloride levels at 19,400 mg/L are much higher than the 1,000 mg/l allowable into the sewage plants considered by the study. Transport to the waste water treatment plants was "not an obvious possibility." The study, after eliminating existing treatment plants from consideration, focused on mobile solutions.

King (2013) focuses on a barge-based solution, noting that the required flow rate for the Port of Baltimore "would be the equivalent of Baltimore's Back Bay" waste water treatment plant. However, the study does not consider the concept in detail.

Literature findings relevant to California include:

- The impact of ballast water chloride levels, potentially reaching 32,000 mg/L, should be considered when evaluating compatibility and potential refit requirements for existing treatment plant piping and processes.
- Similar to new land-based facilities, means of transporting the ballast water to these facilities will require careful consideration of cost, required permits, and impact on port operations. Because these facilities would be existing they may either offer challenges in terms of being remote from the port facilities, or advantages if there is already transport means in place.
- Similar to new land-based facilities, temporary storage may offer a means to avoid peak processing times, either from the existing facility or the ballast water discharges.
- Similar to new land-based facilities, the impact of the new ballast water inputs on existing facility permits should be considered.

3.1.3 Reception and Reuse

Reception and reuse includes operations that *collect ballast water for reuse either as ballast water for another marine vessel*, or for some other purpose. In an ideal scenario, the facility could receive the ballast water from one vessel, and in turn discharge the same ballast water to another vessel.

Hillard (2010) discusses the idealized case of a facility receiving untreated ballast water from one vessel, and supplying treated ballast water to another vessel. However, it notes challenges including cross-contamination between the discharged and treated water, challenges with marine vessel piping systems not being able to receive the treated water, and potential impacts on vessel schedules. Hillard (2010) also discusses the opposite of reception noting that ports might supply vessels with uncontaminated ground water from aquifers. Prince William Sound RCAC (2005) discusses the use of an existing shore-based treatment plant in Valdez, Alaska that for decades treated oily ballast water discharged from crude oil tankers. This fact sheet suggests that such a facility could be retrofitted for reception of ballast water for treating potential aquatic invasive species. RCAC (2005) also considers the use of clean water from municipal water supplies to supply ships with ballast, as currently allowed by federal regulations, and supplying ships with treated, or recycled, ballast water from a shore-based treatment facility.

Both COWI (2012) and BWTBoat (2013) consider the uptake and treatment of water from the port basin and supplying it to ships as ballast. This method differs from RCAC (2005), which considers reception, treatment, and recycling of discharged ballast water. COWI (2012) suggests storing a large volume of treated ballast in storage tanks to meet peak demands for treated ballast water. During slow periods, the study suggests that treatment systems that would otherwise sit idle could continue operating to replenish the storage tanks.

Literature findings relevant to California include:

- The ability for California to accept ballast water treated at another port and supplied to the marine vessel looking to discharge will require a reliable means of verification.
- The supply of ballast water from a port facility, for use at another port facility, requires investment from the supply port with no direct benefit in its own environmental protection.
- The use of reception and holding can significantly dampen peak demand on treatment facilities.

3.1.4 Mobile Facilities

Mobile facilities provide any combination of reception, storage, or treatment of ballast water by a *facility that can be readily positioned to suit a port's logistics*. Variations include using a truck-based treatment plant (COWI, 2012; Damen, 2014), a treatment plant located on board a marine vessel (Brown and Caldwell, 2008; King, 2013; BWTBoat, 2013; Damen, 2014; Top Water Flow, 2015), and a temporary placement onboard the marine vessel itself (IMarEST, 2013),

Brown and Caldwell (2007) found that a barge-based storage and treatment facility has significant advantages over various land-based options. In particular, they found that certain tank barges would have adequate capacity to hold the required ballast water discharge volumes, and that the available deck space would suit the needed treatment units.

COWI (2012) considers two case studies that are identical except for the treatment method used – one uses a barge-based approach and the other truck-based. The second case study finds that, because of the higher capital costs of purchasing a barge over a truck and trailer, the truck-based system is more economically feasible. COWI (2012) shows how the particular characteristics of a port and the type of vessels it serves may dictate which option is more practical.

King (2012) also considers a barge-based approach. However, King notes that, due to the logistical challenges and resulting costs of the shifting mobile facility to various locations throughout the Port of Baltimore, it is "highly unlikely" that investing in a barge-based facility is a viable approach for the port.

For marine vessels in particular, a significant advantage is the storage capacity available. Brown and Caldwell (2007) initially considers using a barge to transport ballast to a land-based facility, but ultimately determines that a typical barge would have more than enough storage to hold the study's design storage capacity and sufficient deck space to accommodate treatment units. Additionally, these studies consider direct water access a major advantage of barges over other shore-based methods. COWI (2012) illustrates this effectively, pointing out that barges can approach ships on the seaward side to avoid inference with cargo operations on the terminal.

Brown and Caldwell (2007) and King (2012) both identify towing services for these barges as the highest operating cost for their barge-based solutions (see Table 22). BWTBoat (2013) trades this operating expense challenge with the higher capital cost of self-propelled barges or boats with mobile treatment units installed.

BWTBoat (2013) contemplates a network of thousands of self-propelled barges or boats that would be required to serve an entire shipping region. A combination of treatment approaches are examined with BWTBoats serving vessels both at uptake and discharge. This study considers the logistics of having a network of facilities operating cooperatively throughout at a large region of ports.

IMarEST (2013) provides a short summary of contingency ballast water treatment systems to the International Maritime Organization, all of which are mobile systems. The noted approaches include the mobile facility by Damen and the BWTBoat, and the prototype system by US National Park Service and US Geological Survey "that is transferred to the marine vessel for in-tank treatment." Contingency approaches are further discussed in Section 4.2.

Mobile treatment systems are also increasingly available in the marketplace. Dutch company Damen Shipyards offers a treatment unit not dissimilar from that described in COWI (2012), suitable for use on a barge or truck trailer (Damen, 2014). Additionally, Norwegian-based Top Water Flow A/S offers a barge-based system that establishes a connection to vessels' ballast discharge system through magnetic connectors, and claims that no vessel modifications are required to use the system (Top Water Flow, 2015).

Literature findings relevant to California include:

- Mobile approaches, regardless of marine vessel based or land-based, offer significant flexibility as may be needed to support the port logistics of certain locations.
- Mobile approaches, in particular barge-based, deserve careful consideration of operating and transportation expenses.
- The storage capacity of barge-based approaches can offer significant advantages in reducing the instantaneous treatment system demand by providing surge capacity.

3.2 Port Logistics

Port logistics considers *the movement, operations, and coordination of the many moving components, both marine and land-based, that occur within port districts*. In addition to cargo operations and any related ballasting operations, port logistics can involve: cargo mobility and readiness; availability of berths and anchorages; dockside labor availability; availability of cranes and other port infrastructure; and coordination of services, such as pilotage, towing/ship assist services, launch services, bunkering operations, and delivery of provisions. Primary factors influencing port logistics include vessel traffic and berth availability. Port logistics takes into account the activities of all vessel types operating in the vicinity, which, in addition to cargo vessels, may include towing vessels, commercial and tribal fishing vessels, recreational vessels, government/military vessels, and passenger vessels.

The impact to port logistics as a result of shore-based ballast water reception and treatment will vary significantly depending on the approach adopted at a given location. For example, offloading ballast water to a new land-based facility by means of an in-ground or above ground piping system will have different impacts when compared to transferring ballast water to a mobile, marine vessel-based solution.

The following aspects of port logistics are reviewed in this section:

- Vessel logistics.
- Ballast water transfer.
- Ballast water storage.
- Ballast water treatment and discharge.
- Handling of residual slurry.

3.2.1 Vessel Logistics

Marine vessel logistics related to shore-based ballast water treatment includes *the coordination of vessel movements to and from marine terminals and other shore-side infrastructure*, and in some cases, alongside other vessels. The objective is to handle the ballast water discharge in a means that is timely, practical, reliable, and safe. Each of the various approaches for shore-based treatment face a different set of logistics requirements. In addition, port and terminal arrangements, as well as vessel types, significantly impact the logistics. This section identifies various findings on vessel logistics in the literature, and highlights relevance to California.

Hilliard (2010) finds in that vessels in the Caspian Region sometimes perform deballasting operations before entering port to reduce their draft. The prevalence of this practice in other regions is not examined in the literature; however, it may be important to consider the practice of deballasting before arrival to reduce draft or to reduce the time spent at berth. In some instances, deballasting may be necessary for deep-draft vessels calling ports or berths with shallow approaches. In such situations, for shore-based treatment to be practicable, a barge- or ship-based treatment system would be necessary to capture any ballast water that must be discharged prior to port entry. As noted in EPA SAB (2011), the feasibility of this method is dependent on the number of vessels annually that practice this at a given port. Considerable operational challenges may arise if a mobile treatment unit must be shuttled to and from shore to serve these vessels frequently. For vessels deballasting in advance of arrival to reduce loading times and total time at berth, modifications could be made to increase pump capacity and ensure deballasting can be completed during cargo operations. Though, if such a vessel were planning to utilize shore-based treatment, modifications – including increased pump capacity to direct ballast to the main deck – would likely be necessary regardless (Brown and Caldwell, 2007). Vessel modifications are discussed in more detail in Section 3.3.

Lightering vessels, which take on cargo from vessels off- or near-shore, typically discharge ballast while doing so. EPA SAB (2011) mentions that the smaller shuttle tankers may be carrying ballast from nearby regions that may not require treatment. However, the ballast practices of the larger carriers that are delivering the cargo, while perhaps only taking up ballast water, need to be confirmed.

Hilliard (2010) offers an interesting example of how seasonal port/waterway closures result in ship congestion in port, both before and immediately following a closure. Similar patterns may exist in areas with highly seasonal cargoes, as well (e.g., agriculture products, fish harvests, etc.). Often though, periods of high vessel traffic are subject to a degree of randomness. COWI (2012) addresses this by implementing a number of "reserve" treatment units in case of unexpected traffic increases. However, reserve units increase capital costs significantly and would likely sit idle for much of the year. BWTBoat (2013) suggests that, in a regional network of shore-based options, ports may be able to share treatment units in order to manage periodic shifts in ballast uptake and discharge demands.

King (2013) notes that bulkers, the vessel type of interest in the study, call to a geographically dispersed set of terminals within the Port of Baltimore. These dispersed locations increases not only the expense of shifting a barge-based treatment system between locations, but may also require multiple units for times when more than one bulker is discharging. Further, the location of the barge alongside the ship during cargo operations requires consideration.

Pereira (2012) notes that, for certain vessel types, cargo operations and deballasting operations are interconnected processes that must be performed such that vessel stability and trim can be maintained. A simulation model was used to determine the time and rate of deballasting at a single terminal, as well as the waiting time between cargo discharge operations. The goal of the simulation model is to more accurately measure the increase in a vessel's time in port due to a shore-based treatment approach. The study finds that minimal delays are introduced in the model, but emphasizes the importance of implementing shore-based treatment such that a vessel's cargo operations are minimally impacted.

Literature findings relevant to California include:

- The practice of deballasting before arrival for vessels calling California ports should be investigated.
- Regulations applicable to the ballast discharge of lightering vessels should be examined. The extent to which lightering vessels discharge ballast in or near California ports should be considered, as well.
- Ballast water discharges may be take place over a large area within port districts. To treat vessels at multiple locations within a port, costs of transporting the mobile treatment

facility, operating multiple treatment facilities, or transporting ballast water to a fixed treatment facility must be considered.

- Ballast water discharges are not always continuous, but rather may be coordinated with cargo operations. Importantly, there will often be surges in discharges when multiple vessels are discharging, as well as lulls when none are discharging.

3.2.2 Ballast Water Transfer

Ballast water transfer considers *the logistics and equipment required to capture the ballast water from the marine vessel and transfer it to a reception and treatment facility*. The transfer operations will vary significantly depending on the selected reception and treatment approach.

3.2.2.1 Capture

Capture is *the method by which ballast water is transferred onto or off a marine vessel*. In the case of a mobile treatment approach, such as in Brown and Caldwell (2008), COWI (2012), King (2013), and BWTBoat (2013), ballast water is captured directly by the reception and treatment facility. In the case of a remote, non-mobile treatment facility, land-based or otherwise, the captured ballast water from the marine vessel must be transported to the treatment location by means such as a barge, truck, railcar, or piping system (see Section 3.2.2.2).

Brown and Caldwell (2008) base all estimates on the use of a marine vessel deck connection with a universal fitting for connecting to shore-based approaches. BWTBoat (2013) and King (2013) also consider a universal deck connection for transferring ballast water both to and from a marine vessel. COWI (2012) suggests that the fixed part of a dry disconnect coupling (DDC) be installed on the ship's discharge piping.

Top Water Flow (2015) considers additional means of connecting to the marine vessel: a magnetic coupling system that, in concept, would allow a mobile barge to connect directly to the hull of the marine vessel at either the ballast water overboard discharge pipe or the seachest where the vessel takes in ballast water. The approach might eliminate the need for the marine vessel to install a new, special deck fitting and associated piping.

King (2013) and Brown and Caldwell (2008) both provide cost estimates for the marine vessel to provide such a deck fitting. These costs range from $60,000 for a small bulk carrier to over two million for a large tank ship. The higher estimates, which King (2013) updates to 2012 dollars from Glosten (2002), consider that the tank ship would need to install larger pumps and ballast water piping to increase pumping rates in order to make-up for lost time due to the inability to discharge ballast water prior to arriving at the cargo terminal.

Literature findings relevant to California include:

- A universal deck connection is the most commonly reviewed capture approach.
- Alternative approaches such as seachest, overboard discharge, mobile on-board, and magnetic connections should also be considered.
- The costs for a refitting a vessel with a universal deck connection and the associated marine vessel piping modifications should be considered.

3.2.2.2 Transport

Transport is *the method by which ballast water is moved post-capture from marine vessels to remote, non-mobile reception and treatment facilities* – either land-based or otherwise. A "remote" facility implies one that is not immediately adjacent to the marine vessel discharging ballast water.

Brown and Caldwell (2007) considers transport via pipeline, railcar, truck, and barge to a remote land-based facility, and notes that existing port infrastructure may dictate which option is the most viable at a given port. The study also points out that, depending on vessel traffic, infrastructure for ballast water transport may often sit idle. This is especially pertinent for pipelines, which may need to link the treatment facility with several marine terminals, but may not receive ballast from all terminals simultaneously or even experience regular use. The study notes that rail infrastructure may already be available in some ports, but small transport volumes could be a limiting factor for this mode of transport. Small transport volumes could be a limiting factor for truck transport as well (Brown and Caldwell, 2007). The study considers barges to be the most viable option for transport at the Port of Milwaukee due to capacity and mobility, but does not provide detail on how ballast water would be transferred to land, as the study ultimately opts to consider treating ballast water directly on the barge instead.

The literature does not address using remote, marine vessel-based treatment facilities. However, transport options should be considered for this approach, as well.

Literature findings relevant to California include:

- Additional port infrastructure may be necessary for transport of ballast water to a remote facility.
- Periods of low utilization of transport infrastructure should be considered.
- The literature does not consider remote, marine vessel-based facilities, but transport infrastructure necessary for this approach warrants investigation.

3.2.3 Ballast Water Storage

Storage of ballast water includes *provision of space and containment for ballast water*, either pre-or post-treatment. Ballast water storage can be employed before treatment to increase flexibility and minimize the required treatment rate (Pereira, 2012), or after treatment if the stored ballast water is to be resupplied to vessels (COWI, 2012 . The literature identifies barges (Brown and Caldwell, 2007), tanks Hilliard, 2010; Pereira, 2012; COWI, 2012), container units (COWI, 2012), and repurposed crude oil carriers (Donner, 2010) as potential storage options.

Pereira (2012) finds that storing ballast water before treatment allows for flexible port operations and lower required treatment rate for a given volume of ballast water. The study uses a simulation model to find the minimum amount of storage capacity and treatment rate necessary to serve the anticipated volume of vessel traffic for two iron ore ports in Brazil. The simulation tracks the tank occupancy over a ten-year period and sizes the storage tanks so that occupancy never rises above a certain percentage. For ports with lower shipping volumes and less frequent vessel traffic, more simplistic methods, such as sizing tanks to hold only a few days' worth of ballast deliveries (as in Hilliard, 2010), are probably sufficient, but may not optimize costs.

COWI (2012) suggests that, for a reception and reuse treatment approach, storage tanks of treated ballast water can be used to meet peak demand periods, and treatment units can continue to operate during slower periods by replenishing these tanks. The study emphasizes that zooplankton regrowth in storage tanks with treated ballast water should be mitigated with chlorine dosing.

Brown and Caldwell (2008) uses a marine vessel-based treatment approach and selects a large capacity tank barge to store ballast water before treatment. The study also considers sending ballast water to a local inline storage system operated by the Milwaukee Metropolitan Sewerage District (which would then be treated at a waste water treatment plant), but determines that the facility may not always have capacity to accept ballast water, and would require pretreatment of the ballast water as well.

COWI (2012), King (2013), and BWTBoat (2013) examine options that forego ballast storage by designing the treatment rate of the system and the discharge rate from ships to be equal.

Literature findings relevant to California include:

- Providing ballast water storage allows for flexible port operations and lower treatment rates.
- Stored, treated ballast water must be dosed with chlorine to prevent zooplankton regrowth. Note the relevant findings to California in Section 3.1.3 that address supply of treated water to marine vessels.
- Certain types of marine vessels offer significant storage capacity and may also be used as treatment facilities.
- Ballast water storage is not necessary if the treatment rate is sufficient to treat ballast at the same rate at which it is captured.

3.2.4 Ballast Water Treatment and Discharge

3.2.4.1 Treatment

Treatment includes *any of the various methods to process ballast water such that it is suitable for discharge in compliance with applicable standards and regulations*. A comprehensive assessment of current marine based ballast water treatment technologies and the ability to meet California's interim discharge standards is presented in CSLC (2014). However, the literature does not review the ability of shore-based approaches to meet the California interim standard.

The literature does provide insight relative to operational considerations and general constraints of various treatment technologies. Those are discussed in this section.

Brown and Caldwell (2007) considers UV disinfection, ozonation, membrane filtration, and hydrodynamic cavitation as potential treatment technologies (each with an initial filtration step to remove large solids). The study notes that the effectiveness of UV disinfection is highly dependent on the UV transmittance of the ballast water treated, which can vary significantly depending on a vessel's port of origin. Brown and Caldwell (2007) find that ozonation may require an oxygen supply tank, depending on the desired dose of concentration of ozone, which would add an additional costs. The study notes that if the membranes used for membrane filtration are to remain unused for extended periods of time (months), they would need to be kept in a chlorinated solution to prevent organism regrowth. The study also notes that a dedicated treatment tank is required for this treatment technology, since the treatment occurs in "batches," with the entire volume of ballast water needing to be stored between batch cycles. In Phase 2 of the study (Brown and Caldwell, 2008), UV disinfection is the chosen treatment technology for the study's preliminary design.

Hilliard (2010) notes that the high turbidity of water in the waterways of the Caspian Region pose challenges for the effectiveness of UV disinfection and would require frequent upkeep of filtration systems. The study also suggests that the high level of suspended sediments in the water require high concentration of chemical oxidants for oxidation treatment technologies; this, combined with the cold temperatures of the of the region's water, may result in the formation of “long-lived by-products” from the treatment process. Hilliard 2010) also considers that the low salinity of water in the region precludes the use of desalination as a treatment technology, but may make the addition of salt a viable technique. Further, the study notes that low levels of halide ions in the region’s water preclude the use of electrolysis to produce oxidants for oxidation treatment.

COWI (2012) opts to use a commercially available treatment unit for their mobile shore-based treatment approach. The unit employs filtration and UV disinfection. The study notes that ozone generated from the UV irradiation is reintroduced into the stream for additional treatment. King (2013) also assumes the use of one or more commercially available filtration/UV treatment units in the study’s barge-based treatment approach.

BWTBoat (2013) observes that UV disinfection and chlorination account for a combined 75% of existing treatment technologies. UV treatment provides nearly instantaneous disinfection of ballast water, but does not provide continuous treatment. If ballast water treated in this way is allowed to sit for long periods after treatment, it is possible for considerable regrowth of zooplankton. Therefore, for vessels embarking on long voyages (several hours or more), treating ballast water on uptake only may not be appropriate if UV disinfection in used. In this case, additional treatment upon discharge would be required (BWTBoat, 2013). Conversely, chlorination methods are not instantaneous, requiring several hours of residence time in tanks, but provide continuous treatment. If introduced on uptake, no further treatment would be required before discharging, though the ballast water would need to be neutralized to reduce residual oxidants left over from the chlorination process.

Literature findings relevant to California include:

- There is a lack of data relative to the shore-based technologies relative to the California interim standard.
- The characteristics of the water to be treated (salinity, UV transmittance, etc.) may determine the best treatment technology for a given application, though this requires specific knowledge about the origin of ballast water arriving to California ports. Consider “mismatches” of water and treatment types, such as low transmittance water and UV treatment.
- If permitting discharge of ballast water previously dosed with chlorine or another oxidant, a port must have a means of verifying that the water has been sufficiently treated and subsequently neutralized before discharge.
- Dedicated treatment tanks may be required for hydrodynamic cavitation.
- Desalination or addition of salt may be a viable treatment technology depending on the salinity of water to be treated.

3.2.4.2 Discharge

Discharge of ballast water is *the method by which post-treatment ballast water is disposed of in compliance with applicable standards and regulations*.

BWTBoat (2013) notes that IMO discharge standards may be different for marine vessel-based and land-based treatment systems. While a marine vessel may discharge ballast water directly to sea directly after treatment, post-treatment ballast water on land may not be considered “ballast water,” and thus may be subject to different regulations (COWI, 2012). COWI (2012) discusses the regulatory distinction between marine vessel-based and land-based facilities in regards to Danish regulatory bodies. The study observes that discharges from a land-based facility would likely fall under municipal waste water regulations, rather than federal or international regulations for ballast water discharge. Regulatory considerations will vary from port to port, and a thorough review of the applicable discharge standards and regulatory requirements for a given port and treatment approach is necessary when assessing the implementation of shore-based treatment.

There are a few options noted in the literature for ballast water discharge aside from simply discharging to sea; these include discharging after treatment to a sewage plant (COWI, 2012), waste water treatment plant (Brown and Caldwell, 2007; COWI, 2012), and to constructed wetlands (Brown and Caldwell, 2007).

Discharge to a sewage or waste water plant is distinct from transporting ballast water to these facilities for treatment. In the present case, the ballast water is already treated, and discharging treated water to a sewage or waste water plant may be necessary if the treated water is no longer considered "ballast water" and cannot be discharged to sea. Both Brown and Caldwell (2007) and COWI (2012) note that the high salinity of the ballast water discharged is not permissible for such facilities, however.

Though Brown and Caldwell (2007) raises the idea of discharging to constructed wetlands, the study does not mention what advantages this method might have and dismisses it for the Port of Milwaukee, as there is not sufficient port-owned land available.

Literature findings relevant to California include:

- Regulations for the discharge of ballast water from a land-based facility may fall under a combination of municipal, state, and federal requirements. Applicable waste water regulations for California ports must be considered.
- Salinity of ballast water may prohibit discharge to existing sewage or waste water treatment facilities.

3.2.5 Handling of Residual Slurry

Slurry handling includes *the storage, treatment, and discharge of residual slurry resulting from backflushing of treatment filtration units*. This is only an issue for treatment on discharge. Typically, if ballast water is treated upon uptake, the slurry is discharged back to its point of origin.

Brown and Caldwell (2007) notes that the slurry must be appropriately treated and stored to prevent any possibility of transmitting invasive species to the port basin. COWI (2012) specifies that both a reception and treatment tank should be employed to properly handle residual slurry.

COWI (2012) suggests treating the slurry via chlorination. After treatment, is the slurry is allowed to settle and the supernatant liquid can be neutralized and discharged appropriately. The study notes that discharge of the supernatant liquid may be subject to additional regulations, similarly to the regulations discussed treated ballast water in the preceding section.

For discharge of the remaining sediments, COWI (2012) considers several options (see Section 2.4.2.2), but determines that landfill disposal is the most feasible one, assuming proper permits are obtained and the sediments included on the site's acceptable discharge list. Other options considered "possibly feasible" are discharge to a hazardous waste incineration facility and a normal incineration facility. COWI (2012) deems the former to be too expensive, while chlorine content may be an issue for the latter option.

Literature findings relevant to California include:

- Relevant literature findings from Section 3.2.4.2 apply to the supernatant liquid from resulting from slurry treatment.
- It may be feasible to dispose of remaining sediments to a landfill. Appropriate regulations and acceptable discharges to landfills in California must be investigated.

3.3 Vessel Modifications

Vessel modifications include *retrofitting of a marine vessel's piping systems, or other installations that may be necessary to capture ballast water from a vessel and transport it to a shore-based treatment facility*. Two notable exceptions where vessel modifications may not be required are discussed in Section 4.2.

Brown and Caldwell (2008) offers a detailed examination of vessel modifications and provides corresponding cost estimates. The study bases its estimates on a general cargo ship, *Federal Pioneer*, and a larger, hypothetical vessel. The former has 18 ballast tanks with total capacity of 5,700 MT and the latter is assumed to have 30 tanks with total capacity of 18,000 MT. Vessel modifications for the *Federal Pioneer* and the larger are estimated to be $60,000. For larger, hypothetical vessel, modification costs are estimated to be $204,000. The study provides a breakdown of the costs considered, including materials and installation, with allotment for contingencies and technical services. These estimates are summarizes in Table 22. Notably, Brown and Caldwell (2008) determines that the pump capacity on both the *Federal Pioneer* and the larger ship are sufficient to reroute ballast water up to the vessels' main decks, and thus does not consider the purchase and installation of new pumps in the cost estimates provided. Brown and Caldwell (2008) also estimate that vessel modifications would take roughly 5 – 17 days, assuming the shipyard commits 12 people working eight-hour shifts to the retrofit. The study notes that modifications could also be made during a regularly scheduled shipyard period.

Though no estimates are performed directly, King (2013) updates cost estimates from Glosten 2002) to 2012 dollars, as summarized below:

- Tankers: $2,433,000
- Grain ships: $137,000
- Break bulk: $390,000
- RoRo: $207,000

It is evident from this and the estimates in Brown and Caldwell (2008) that the cost of vessel modifications depends on the type of vessel and the capacity of its current piping system.

Additionally, the literature suggests that vessels intending to use shore-based treatment install a universal deck connection (Brown and Caldwell, 2008; King, 2013, BWTBoat, 2013). A universal standard has yet to be established for this purpose, but BWTBoat (2013) suggests adopting standards used by the Oil Companies International Marine Forum (OCIMF).

Literature findings relevant to California include:

- The connection point is crucial for shore-based ballast water treatment, as there is zero tolerance for leakage of untreated ballast water.
- Cost of vessel modifications varies dramatically with vessel type.
- Alternative approaches that eliminate the need for vessel modifications have been identified in the literature, but no studies were found that demonstrate their effectiveness.

Table 21 Summary of port, vessel, and treatment system characteristics of the selected feasibility studies

	Brown and Caldwell (2008)	Hilliard (2010)	Pereira (2012)	COWI (2012)	King (2013)	BWTBoat 2013)	Relevance to California Shore-based BWT Evaluation
Port Characteristics							
Port(s) of Interests	Port of Milwaukee	Caspian Region Ports	1. Port of Tubarão 2. Port of Sepetiba	1. Port of Esbjerg 2. Port of Fredericia	Port of Baltimore	1. Asia/Oceania Ports 2. European Ports	The variety of port sizes offers inputs for considering CA locations.
Total Cargo Tonnage	Not considered	Not considered	1. 90,000,000 MT 2. 25,000,000 MT	Not considered	Not considered	Not considered	
Annual Vessel Calls	85	~240 voyages to/from region (~1 per day, when open)	1. 596 2. 162	1. 1,175 2. 520	282 (50)*	1. 18,445 2. 15,770	Range of total vessel calls considered in the literature may be useful when performing scale up.
Annual BW Discharged	Not considered	280,780 MT (~2,000 MT/day)	1. 27,000,000 MT 2. 7,500,000 MT	Not considered	7,876,690 MT*	Not considered	Volumes considered vary greatly and influence the treatment/storage approach.
Vessel Characteristics							
Typical Vessel Type(s)	Grain carriers	"River-Sea" Ships (general cargo ships and tankers)	Iron ore carriers	Ro-Ro freight ferries Offshore platform service vessels General cargo ships	Bulkers	All vessels over 400 gross tons	The vessel types have significant overlap with CA vessel calls. The lightering cases in Hilliard bear consideration when exploring CA lightering.
Vessel DWT	Not considered	Not considered	1. 40,000 – 400,000 DWT 2. 60,000 – 200,000 DWT	Not considered	Not considered	Vessels of all DWT ranges are considered	
Vessel BW Capacity	5,700 – 17,800 MT	500 – 2,300 MT Avg. 1,700 MT)	1. 12,000 – 120,000 MT 2. 18,000 – 60,000 MT	Avg. of 250 – 300 MT discharged per vessel call	70,000 MT	Variable, not specified	Variety of ranges are applicable to CA. BWTBoat scale-up methods are helpful.
BW Discharge Rate	560 – 2,250 MT/h	100 – 500 MT/h	Up to 5,000 MT/h	300 MT/h	Not specified	Variable, not specified	Range is applicable to CA.
Treatment Approaches							
Treatment Method	Barge	Land-based facility	Not considered	Truck Unit; Barge	Barge	Self-propelled Barge	Consider shore connect details for each.
Treatment Technology	Filtration + UV	Considered, but not specified	Not considered	Filtration + UV	Filtration + UV	Filtration + UV/Chlorination	Discussions on impact of water quality useful when considering technologies.
Treatment Rate	225 MT/h	2,000 MT/day	1. 5,000 MT/h 2. 2,000 MT/h	300 MT/h	20,000 MT/h	Not specified	Range of rates useful when considering CA possible solutions.
Treatment time per ship	Two days	5 – 10 h	Avg. 17 h	1.75 – 2 h	10-h cargo operations per ship	Variable, not specified	Focus on turn-around time for vessel traffic is important.
Storage Capacity	Ballast: 10,200 MT Residual slurry: Not specified	Ballast: 6,000 MT Residual slurry: Not considered	1. 40,000 MT 2. 20,000 MT Residual slurry: Not considered	Ballast: None Residual slurry: 32 m^3	Not considered	Not specified	The use of storage capacity to reduce instantaneous treatment loads may be applicable to many CA locations.
Design Life	20 years	15 – 20 years	10-year simulation period	15 years	20 years	Not considered	
Discharge Method	Ballast: To sea Residual slurry: Not specified	Ballast: Not specified Residual slurry: Land fill	Not considered	Ballast: To sea Residual slurry: Land fill	Not considered	Ballast: To sea Residual slurry: To sea (on uptake)	CA outfall considerations will be informed by the literature, especially the use of landfills.

*282 vessels call to the port, annually, but 50 are estimated to require contingency treatment. 7,876,690 MT is the total annual amount of ballast water discharged, not the amount that would be treated by the contingency system.

Table 22 Summary of cost estimates of the selected feasibility studies (not adjusted to 2015 dollars)

	Brown and Caldwell (2008)		COWI (2012)*		King (2013)		Relevance to California Shore-based BWT Evaluation
	20-year life-cycle; 5% annual interest Barge-Based Treatment System		Annual expenses in Danish Kroner DKK Truck-Based Treatment System		Annualized based on 20-year life-cycle; 5% annual interest Barge-Based Treatment System		
Treatment Approach	**$3,522,000**		**4,200,000 DKK**		**$312,500/year**		
	Treatment unit	**$813,000**	**Treatment unit**	**2,400,000**	**Treatment unit**	**$168,500**	The range of cost estimates indicate that there remains a high level of uncertainty in determining not only the cost of treatment systems, but especially of means of conveyance.
	Purchase/construction	$625,000	**Mobile unit**	**1,300,000**	Annual debt payments for purchase and installation of two treatment units		
	Technical services	$188,000	Flatbed trailer	200,000	**Barge**	**$144,000**	
	Barge	**$2,709,000**	Spare parts	150,000	Annual debt payments on purchase		
	Purchase	$2,000,000	Generator	200,000			
	Modifications	$238,000	Truck unit for transport	750,000			
	Technical services	$71,000	**Storage**	**500,000**			
	Transport	$400,000	32-m^3 tank	50,000			
			150-m^3	300,000			
			Misc. costs	150,000			
Operating Costs	**$6,416,000**		**1,500,000 DKK/year + 2.10 DKK/t**		**$606,000/year**		
	Towing Present Worth	**$4,391,000**	**Labor**	**1,500,000**	**Annual Towing Cost**	**$330,000**	The operating costs indicate a high level of uncertainty, especially in terms of towing and labor. The concept of engaging third parties for running such facilities merits evaluation, especially given the potential impact on cost and reliability. The issues associated with idle facilities in locations with infrequent vessel calls should be considered, not only relative to costs but also on how such costs might impact those locations where the average per service cost would be much higher than in high volume locations.
	Annual Towing Cost (85 tows)	$357,000	Operators	1,200,000	**Annual Labor**	**$260,000**	
	Cost per tow	$3,000	Manager	300,000	Operators	$160,000	
	Fuel per tow	$1,200	**Variable Costs**	**2.10 DKK/t**	Manager	$100,000	
	O&M Present Worth	**$1,968,000**	Power	0.50	**Annual barge docking fees**	**$6,000**	
	Annual O&M	$160,000	Maintenance	0.60	**Annual barge maintenance**	**$10,000**	
	Energy usage	$113,000	Fuel for truck	0.40			
	Labor	$34,000	Slurry transport	0.40			
	Chemical cleaners	$3,000	Depot fee	0.20			
	Equipment maintenance	$10,000					
	Equipment replacement	$57,000					
Vessel Modifications	**$60,000 - $204,000**		**Not Estimated**		**Updates estimates from Glosten (2002) to 2012 dollars**		
Small vessel: 18 tanks with total ballast capacity of 5,700 MT.	**Small Vessel**	**$60,000**			Tanker	$2,433,000	The vessel modification costs updated by King (2013) were performed in 2002 and vary significantly from the those in Brown and Caldwell (2008). In general, vessel modification costs may vary depending on vessel type, size, age, and numerous other factors. Evaluation of vessel modification costs for vessels calling to California ports warrants careful review and consideration, and cannot be determined solely from estimates provided in the literature.
	Materials	$13,400			Grain ship	$137,000	
	Installation	$23,600			Break-bulk	$390,000	
	Contingencies	$9,000			RoRo	$207,000	
	Technical Services	$14,000					
Large vessel: 30 tanks with total ballast capacity of 18,000 MT.	**Large Vessel**	**$204,000**					
	Materials	$45,500					
	Installation	$80,000					
	Contingencies	$31,400					
	Technical Services	$47,100					

*Refer to Section 2.4.3 for cost estimates of each of the business cases considered in COWI (2012), and Section 2.4.4 for a summary for the study's financial analysis results.

Section 4 Supplementary Issues

The primary themes of reception and treatment approaches, port logistics, and vessel modifications are discussed in terms of their relevance to California ports in the previous section. This section identifies supplementary issues discussed in the literature that might also have an impact in the assessment of potential shore-based treatment approaches in California.

4.1 Burden of Responsibility

A common perception in the literature is that ports will take on the costs of implementing shore-based treatment approaches (Phillips, 2005/6). While it is intuitive that ports want to ensure that their region is protected from non-native species, this does not necessarily imply that a port must bear the entirety of the burden.

COWI (2012) suggests that stevedoring companies might have an interest in integrating ballast treatment into their business plans. A fleet operator may see advantages in such an investment if a single shore-based facility could serve a significant number of vessels that would otherwise each need to be equipped with a shipboard system, as in COWI (2012) or BWTBoat (2013). In this case, the treatment operator may have the opportunity to, in addition to providing treatment to its own ships, charge a fee for other ships to receive treatment as well (COWI, 2012). One underlying principle, as pointed out by BWTBoat (2013), is that shore-based treatment has the potential to provide consistent revenues. While there is disagreement in the literature about whether the revenues for shore-based treatment are sufficient to make the operation profitable, there may be incentive for other stakeholders, not just ports, to invest in shore-based facilities and enter the market.

Notably, liability for mistreatment of ballast water remains a major barrier that could discourage potential treatment providers (IMO GIA 2012). Also worth noting is that none of the feasibility studies that develop cost estimates for shore-based treatment consider insurance rates or fines that might be incurred for non-compliance with ballast water regulations or other possible requirements inherited by transferring the ballast water to a shore-based facility.

Literature findings relevant to California include:

- Third parties may be interesting in becoming contractors for ballast water treatment operations to capitalize on potential revenues. This possibility should be investigated to determine the level of interest and economic feasibility at California ports.
- Insurance rates and potential non-compliance fees should be included in future feasibility studies of shore-based treatment approaches at California ports.

4.2 Shore-Based Contingency Treatment

Contingency treatment systems provide backup treatment methods in cases of non-compliance or inability to comply with applicable discharge standards. Typically, these systems are shore-based and relevant to potential approaches for meeting the California interim standard.

One driver for such contingency systems considers that after state, federal, and international regulations enter into force, supply and installation of marine vessel based treatment systems may not be able to meet demand (King, 2013). Additionally, treatment systems may malfunction or experience maintenance or other issues that prevent proper treatment of ballast water IMarEST, 2013; King, 2013).

King (2013) asserts that the feasibility of contingency options is challenged by considerable uncertainty of demand, which will depend on the availability and reliability of shipboard equipment and as yet unresolved questions related to the expected costs of non-compliance. The study notes that it is difficult to predict how many ships will be unable to properly treat ballast water in the early years of regulatory implementation. King (2013) also points out that the treatment technologies used in shore-based systems are likely to be larger versions of the same technologies used in shipboard systems, and thus may be subject to the same anticipated malfunctions and supply issues.

A potentially viable contingency approach is to provide a shore-based contingency option in addition to dedicated services to a particular fleet or subset of vessels in a region (COWI, 2012). COWI (2012) suggests that a number of "reserve" vessels should be implemented for a shore-based operation to avoid delays in periods of high demand, and that these units could also be mobilized in contingency situations, as well. BWTBoat (2013) also notes the possibility of using its marine vessel-based treatment approach for contingency treatment measures.

Shore-based treatment as a contingency measure for the inability to comply with applicable discharge standards was the topic of two recent expert workshops – the first in Singapore and the second in Busan (IMO GIA 2012 and 2013, respectively) – and discussion of the issue took place at the 1st Session of the IMO Sub-Committee on Pollution Prevention and Response IMarEST, 2013). Discussed systems include:

- A barge-based system with a magnetic connection system that would allow ships to transfer ballast water to the barge without any modifications (Top Water Flow, 2015). A mechanical arm on the barge could establish a connection to the ship's normal overboard discharge point.
- A contingency system currently being prototyped by the National Parks Service and US Geological Survey. This approach brings a portable treatment system directly onboard a vessel for in-tank treatment and neutralizaton. This eliminates the need for a capture system.
- The Damen and BWTBoat approaches discussed in Section 3.1.4.

A consideration not examined in the literature is that it is also unclear how demand will change as shipboard technologies and operations mature and penalties for non-compliance are clarified. A large demand for contingency treatment early on may leave a surplus of shore-based treatment units after the shipboard market has stabilized and shipboard treatment systems are made more reliable.

Literature findings relevant to California include:

- Economic viability of a contingency treatment approach is unknown due to high uncertainty in demand as regulatory requirements enter into force and the market develops.
- Contingency treatment may be provided in addition to a dedicated shore-based treatment approach, if demand permits and treatment capacity is available.

4.3 Repurposing of Treated Ballast Water

In addition to collecting and treating ballast water for reuse as another marine vessel's ballast, the literature suggests some alternate uses for the treated water.

Donner (2010) suggests that ballast water could be desalinated, treated via chlorination, and used as fresh water for household or agricultural use in areas where fresh water is scarce. Donner

(2010) notes that desalination is a treatment technology in itself, and that desalinating large quantities of water is likely feasible considering that large cruise ships have the capacity to desalinate more than 3,000 MT of seawater per day. Furthermore, RoyalHaskoningDHV (2014) mentions that export of irrigation-quality, fresh ballast water to the Middle East and Western Australia has been proposed at the Port of Rotterdam.

Repurposing of ballast water could be attractive in areas such as California that receive large amounts of ballast water and are prone to drought. Notably, a major water desalination facility, the Carlsbad Desalination Plant, is scheduled to begin operations in San Diego County before the end of the year, and will be capable of processing more than 350,000,000 MT of seawater per day (Little, 2015).

Literature findings relevant to California include: the feasibility transferring treated or untreated ballast water to a desalination plant, or, similarly, establishing such a facility on a smaller scale to treat and repurpose ballast water from a particular port or collection of ports, should be given further consideration in California.

Section 5 References

1. Albert, R.; Everett, R.; Lishman, J.; Smith, D.; *Availability and Efficacy of Ballast Water Treatment Technology: Background and Issue Paper*, US Environmental Protection Agency, June 2010.

2. Brown and Caldwell, Bay Engineering, Inc; *Port of Milwaukee Off-Ship Ballast Water Treatment Feasibility Study Report, Phase 2*, prepared for the Wisconsin Department of Natural Resources, 28 August 2008.

3. Brown and Caldwell, *Port of Milwaukee Onshore Ballast Water Treatment–Feasibility Study Report*, prepared for the Wisconsin Department of Natural Resources, 12 October 2007.

4. California State Lands Commission (CSLC), *2010 Assessment of the Efficacy, Availability and Environmental Impacts of Ballast Water Treatment Systems for Use in California Waters*, produced for the California State Legislature by the California State Lands Commission, August 2010.

5. California State Lands Commission (CSLC), *2013 Assessment of the Efficacy, Availability and Environmental Impacts of Ballast Water Treatment Systems for Use in California Waters*, produced for the California State Legislature by the California State Lands Commission, June 2013.

6. California State Lands Commission (CSLC), *2014 Assessment of the Efficacy, Availability and Environmental Impacts of Ballast Water Treatment Systems for Use in California Waters*, produced for the California State Legislature by the California State Lands Commission, August 2014.

7. COWI A/S, *Ballast Water Treatment in Ports - Feasibility Study*, prepared for the Danish Shipowners' Association, November 2012.

8. Damen Shipyards Group, *Mobile Ballast Water Discharge Technology: Invasave 300*, marketing sheet, March 2014.

9. Dobbs, F. C.; Rogerson, A.; "Ridding Ships' Ballast Water of Microorganisms," *Environmental Science and Technology*, American Chemical Society, pp. 259A-264A, 15 June 2005.

10. Dobroski, N.; Scianni, C.; Falkner, M.; *Assessment of the Efficacy, Availability and Environmental Impacts of Ballast Water Treatment Systems for Use in California Waters*, produced for the California State Legislature by the California State Lands Commission: Marine Facilities Division, December 2007.

11. Dobroski, N.; Scianni, C.; Takata, L.; *2011 Update: Ballast Water Treatment Systems for Use in California Waters*, prepared for the California State Lands Commission by the Marine Invasive Species Program, 16 August 2011.

12. Donner, P.; "Ballast Water Treatment Ashore Brings More Benefits," Emerging Ballast Water Management Systems, Proceedings of the IMO-WMU Research and Development Forum (Malmo, Sweden), 26-29 January 2010.

13. Environmental Protection Agency Science Advisory Board (EPA SAB , *Efficacy of Ballast Water Treatment Systems*, EPA-SAB-11-009, 12 July 2011.

14. Falkner, M.; Takata, L.; Gilmore, S.; *Performance Standards for Ballast Water Discharges in California Waters*, produced for the California State Legislature by the California State Lands Commission: Marine Facilities Division, January 2006.

15. The Glosten Associates, *Pacific Ballast Water Treatment Pilot Project. Ballast Water Transfer Study: Technical Feasibility with Associated Capital Costs*, prepared for the Port of Seattle, 23 January 2002.

16. Gollasch, S.; David, M.; Voigt, M.; Dragsund, E.; Hewitt, C.; Fukuyo, Y.; "Critical review of the IMO international convention on the management of ships' ballast water and sediments," *Harmful Algae*, 6(585-600), 2007.

17. Hilliard, R. W.; Matheickal, J. T.; *Alternative Ballast Water Management Options for Caspian Region Shipping: Outcomes of a Recent CEP/IMO/UNOPS Project*, Emerging Ballast Water Management Systems, Proceedings of the IMO-WMU Research and Development Forum (Malmo, Sweden), 26-29 January 2010.

18. Hilliard, R. W.; Kazansky, O.; *Assessment of Shipping Traffic and Ballast Water Movements to and from Caspian Region, and preliminary appraisal of possible Ballast Water Management Options*, IMO/UNOPS/CEP Project Technical Report IMO RER/03/G31, 5 November 2006.

19. IMO Global Industry Alliance (IMO GIA), "Report on the 2nd Expert Workshop on Port-Based BWM Contingency measures in Busan, Republic of Korea," IMO Global Industry Alliance, 24 October 2013.

20. IMO Marine Environmental Protection Committee (IMO MEPC), *Ballast Water Treatment Boat (BWTBoat)–a viable alternative for effective and faster implementation of the BWM convention (submitted by India)*, MEPC 65/2/20, 22 March 2013.

21. Institute for Marine Engineering, Science and Technology (IMarEST), *Additional Guidelines for Implementation of the BWM Convention: Contingency Measures for Ballast Water Management*, submitted to the IMO Sub-Committee on Pollution Prevention and Response, PPR1/INF.5, 27 November 2013.

22. Kazumi, J.; "Ballast Water Treatment Technologies and Their Application for Vessels Entering the Great Lakes via the St. Lawrence Seaway," Transportation Research Board Special Report 291, Great Lakes Shipping, Trade, and Aquatic Invasive Species, May 2007.

23. King, D.; Hagan, P.; "Economic and Logistical Feasibility of Port-based Ballast Water Treatment: A Case Study at the Port of Baltimore (USA)," MERC Ballast Water Economics Discussion Paper No. 6 (Review Draft), 7 May 2013.

24. King, D.; Riggio, M.; Hagan, P.; "Preliminary Cost Analysis of Ballast Water Treatment Systems. Maritime Environmental Resource Center Ballast Water Economics Discussion Paper No. 1," 2009.

25. Lee II, H; Reusser, D.; Frazier, M. R.; Ruiz, G.; “Density Matters: Review of Approaches to Setting Organism-Based Ballast Water Discharge Standards,” US Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Research Laboratory, Western Ecology Division, EPA/600/R-10/031, 2011.

26. Little, Amanda, “Can Desalination Counter California's Drought?” The New Yorker, Conde Naste, 22 July 2015, http://www.newyorker.com/tech/elements/can-desalination-counter-the-drought, accessed 28 Aug. 2015.

27. Liu, S.; Zhang, M.; Li, X.; Tang, X.; Zhang, L.; Zhu, Y.; Yuan, C.; “Technical feasibility study of an onshore ballast water treatment system,” *Frontiers of Environmental Science & Engineering in China*, 5(4), pp.610-614, December 2011.

28. National Ballast Information Clearinghouse, *NBIC Data Use Statement and Disclaimer*, Electronic publication, Smithsonian Environmental Research Center & United States Coast Guard, http://invasions.si.edu/cgi/search-nbic?do=agreement, accessed 2 September 2015.

29. Pereira, N. N.; Brinati, H. L.; “Onshore ballast water treatment: A viable option for major ports,” *Marine Pollution Bulletin*, 64(2296-2304), 2012.

30. Phillips, S.; “Ballast Water Issue Paper: Management Technologies, Shore Based Treatment, Hull Fouling and NOBOBs, Regulations, Legislation,” Pacific States Marine Fisheries Commission, August 2005 (Updated Jan. 2006).

31. Port of Rotterdam Authority, *2010 Port Waste Reception Handling Plan*, 3 October 2009.

32. Prince William Sound Regional Citizens' Advisory Council (PWSRCAC), *Ballast Water Treatment Methods – Fact Sheets*, 29 January 2005.

33. Royal HaskoningDHV, *Ballast Water Management Infrastructure Investment Guidance*, prepared for European Bank for Reconstruction and Development, 2014.

34. Satir, T.; “Ship's Ballast Water And Marine Pollution,” Integration of Information for Environmental Security, NATO Science for Peace and Security Series C: Environmental Security, pp 453-463, 2008.

35. Top Water Flow A/S, http://www.topwaterflow.com/, accessed 28 August 2015.

36. Tsolaki, E.; Diamadopoulos, E.; “Technologies for ballast water treatment: a review,” *Journal of Technology and Biotechnology*, 85(1), pp. 19-32, January 2009.

37. Waite, T.D.; “Report on the Workshop on Port-Based Emergency/Contingency Measures for BWM in Singapore,” IMO Global Industry Alliance, 12 November 2012.

38. Wright, D. A.; “Logistics of shipboard and dockside testing of ballast water treatment systems in the United States,” *Biological invaders in inland waters: Profiles, distribution, and threats,* Invading Nature - Springer Series in Invasion Ecology, Volume 2, pp 657-668, 2007.