EPA SAB Ballast Water Advisory

Draft text: Onshore Treatment for Draft Subgroup 3, Outline Section VI.

Prepared by Andrew Cohen.

VI. Onshore Treatment

Onshore treatment includes both treatment facilities built on land and treatment facilities installed on a port-based treatment ship, which will be referred to as "on-land" and "treatment ship" approaches, respectively. Some reports have taken onshore treatment to mean the treatment of ballast water in existing wastewater treatment plants. This is treated here as a special case of on-land treatment which may or may not be feasible in specific circumstances. Currently, some oil-contaminated ballast water is discharged to on-land facilities designed to separate hydrocarbons from the water. Some studies have considered whether it might be possible to modify such facilities to also remove or kill organisms in ballast water, and this is also treated here as a special case of on-land treatment. Some reports have also considered onshore treatment plants as a possible source of clean water that could be loaded by ships as ballast and then discharged without further treatment, or as a source of hot water that could be pumped into a ship's partially empty ballast tank to kill the organisms in the tank (=external source treatment, Aquatic Sciences 1996). These approaches are not considered to be onshore treatment in this report. The discussion of onshore treatment in this report and the assessments of its costs and capabilities refer to treatment in onshore facilities that are built specifically and solely to receive and treat ships' ballast water in order to remove or kill the organisms contained in the ballast water, except where explicit reference is made to treatment in existing on-land treatment facilities.

The discussion includes a review of the literature on onshore treatment, a summary of advantages relative to shipboard treatment and of operational or other issues that could make onshore treatment challenging, an analysis of costs relative to the costs of shipboard treatment, and an initial assessment of the capability of different configurations of onshore treatments to meet various levels of discharge standard.

VI.A. Studies of Onshore Treatment

Onshore treatment has been mentioned or briefly commented on in several studies and reports, but significantly analyzed in only a few (Table VI.A-1). Some of these reports reached conclusions about the feasibility of onshore treatment, stating that onshore treatment is a technically feasible option either for the industry as a whole or for some part of the industry (NRC 1996; Oemke 1999; CAPA 2000; California SWRCB 2002; Brown & Caldwell 2007, 2008), and none showed that it is technically infeasible for any part of the industry. A few concluded that cost or other factors could limit its use to part of the industry, but provided no

data or analyses to support these conclusions (Victoria ENRC 1997; Dames & Moore 1998, 1999; Rigby & Taylor 2001a,b; California SLC 2009, 2010). Gauthier & Steel (1996) stated that onshore treatment is "considered a poor option," citing Pollutech (1992) who draw no such conclusion but rather rank onshore treatment higher than nearly all shipboard approaches. Dames & Moore (1999) stated that onshore treatment is "considered to be less favorable than on-board treatment options" without saying who considers it so; Dames & Moore (1998) identified the source of this opinion as Oemke (1999),[1] who however makes no such statement.[2] Notably, the reports prepared by the U.S. EPA or the U.S. Coast Guard that deal with ballast water management do not contain any analyses or significant discussions of onshore treatment (e.g. it is mentioned briefly in US EPA 2001, mentioned in a single sentence in Albert et al. 2010, and not mentioned at all in a discussion of ballast treatment technologies in US Coast Guard 2008).[3]

Table VI.A-1. Reports that discuss onshore treatment.

[1] Cited "in review" in 1998.

[2] Oemke (1999) cites several advantages of onshore treatment (use of treatments not feasible on ships, easy adjustment of pH to optimal treatment conditions, easy removal of oxidant residuals), notes that it is a "very attractive" option for the VLCC portion of the fleet, but suggests that it will not be widely used otherwise because of ships' practice of partially deballasting while approaching berths.

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

1

Report	Discussion	Conclusions
Pollutech 1992	Compares and ranks various shipboard and onshore treatment approaches.	Onshore ranks 2nd out of 24 options, ahead of all but one shipboard system.
AQIS 1993a	Compares shipboard, on-land and treatment ship approaches.	On-land and treatment ship are cheaper and more effective than shipboard.
AQIS 1993b	Briefly discusses treatment ship and on-land treatment.	Onshore treatment is unlikely except in special circumstances.
Aquatic Sciences 1996	Compares shipboard, treatment ship, on-land and external source treatment.	Onshore is technically feasible and the most effective and cheapest approach.
NRC 1996	Briefly discusses advantages and disadvantages of onshore treatment.	Onshore remains an option.
Gauthier & Steel 1996	Mentions shipboard, treatment ship and on-land approaches.	Onshore is considered a poor option.
Victoria ENRC 1997	Briefly discusses onshore treatment.	Onshore is probably too costly at a large scale; may be viable at a smaller scale.
Greenman et al. 1997	Student report commissioned by the U.S. Coast Guard, largely reprising AQIS 1993a.	???
Cohen 1998	Briefly discusses advantages and disadvantages of onshore treatment.	Onshore has many advantages and few disadvantages compared to shipboard.
Reeves 1998, 1999	Briefly discusses onshore treatment.	Lists onshore as an alternative.
Oemke 1999	Briefly discusses advantages and disadvantages of onshore treatment.	Onshore is feasible for some parts of the industry, such as VLCCs.
Dames & Moore 1998, 1999	Briefly discusses onshore treatment.	Onshore may be good option at oil export terminals with oil stripping plants.
Cohen & Foster 2000	Briefly discusses advantages and disadvantages of onshore treatment.	???
CAPA 2000	EPA-funded study estimates the cost of onshore treatment for California.	Onshore is technically feasible.
Rigby &	Briefly discusses onshore treatment.	Cost, availability, quality control may prevent onshore development, but it

Taylor 2001a,b		might work for tankers that discharge oily ballast to onshore facilities.
US EPA 2001	Briefly mentions onshore treatment.	
California SWRCB 2002	Briefly discusses onshore treatment.	Onshore is an attractive option, at least for some parts of the industry.
Hurley & Ackers 2002	Estimates upper-bound retrofit costs to discharge ballast to onshore facilities.	
NSF 2003	Mentions shipboard, onshore and operational options for the longer term.	Shipboard seems the most challenging approach.
Brown and Caldwell 2007, 2008	Develops designs and estimates costs for onshore treatment at Milwaukee.	Onshore is feasible; treatment ship is cheaper than on-land.
California SLC 2009, 2010	Briefly discusses advantages and disadvantages of onshore treatment.	Onshore might be suitable for terminals with regular vessel calls such as cruise ships, or for the Port of Milwaukee.

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

AQIS (1993a) developed conceptual designs and cost estimates to compare shipboard, on-land and treatment ship approaches to treating the ballast water discharged from 140,000-ton bulk carriers carrying 45,000 MT of ballast water with a ballast pumping rate of 4,000 MT/h. The shipboard system that was analyzed consisted of a 50-µm in-line strainer employed during ballasting, plus the installation of high-level ballast tank offtake pipes to reduce the discharge of ballast sediments and settled cysts or spore stages. The cost of pump upgrades that might be needed to address head loss from the strainers was not included. The on-land facility was designed to handle the discharge from three bulk carriers per week and included 52,000 MT storage capacity and coagulation, flocculation, granular filtration and UV disinfection at a maximum treatment rate of 830 MT/h, with thickening, dewatering and land-fill disposal of residuals. The cost of land acquisition, of the pipes needed to carry ballast water from the berths to the treatment plant, and of onboard pipe modifications and possible pump upgrades needed to allow discharge of ballast water at berths were not included. The

treatment ship alternative was based on converting a used 12,500 DWT bulk carrier and installing 4,000 MT of storage capacity and a treatment system similar to the on-land system but with a maximum treatment rate of 4,000 MT/h and using pressurized granular filters. The cost of onboard pipe modifications and possible pump upgrades needed to allow discharge of ballast water to the treatment ship were not included. The cost estimates are summarized in Table (b)-2. The number of distinct ships treated by the onshore facilities, assuming that each vessel visits once a month, is 10 for the on-land facilities, and 12 and 20 for the two treatment ship scenarios. The annualized costs per 1,000 MT of ballast water treated are thus 13-20 times greater for shipboard than on-land, and 8 and 19 times greater for shipboard than treatment ship in the two treatment ship scenarios (Table VI.A-2).

Table VI.A-2. Treatment cost estimates for shipboard, on-land and treatment ship approaches (AQIS 1993a). The figures have been adjusted to June 2010 US dollars and annualized as described in Appendix 1.

	Capital Costs				
Treatment System	**Storage**	**Treatment**	**Vessel Retrofit**	**Operating Cost ($/1000 MT)**	**Annualized Cost ($/1000 MT)**
Shipboard [1] - 1 ship	0	2,040,844	0	82	508
Shipboard [1] - 10 ships	0	20,408,440	0	82	4,339
Shipboard [1] - 12 ships	0	24,490,128	0	82	5,190
Shipboard [1] - 20 ships	0	40,816,880	0	82	8,596
On-land [2]	3,061,266	6,122,532	2,040,844	92	218
On-land [3]	6,122,532	6,122,532	2,040,844	92	253
On-land [4]	3,061,266	16,326,752	2,040,844	92	333
Treatment ship [5]	8,673,587	12,755,275	2,449,013	422	683
Treatment ship [6]	8,673,587	12,755,275	4,081,688	276	446

[1] Treating 0.5 million MT/y, or about 1 voyage/month.
[2] Treating 5.5 million MT/y, with 52,000 MT storage in earthen basins and 830 MT/h treatment rate.
[3] Treating 5.5 million MT/y, with 52,000 MT storage in steel tanks and 830 MT/h treatment rate.
[4] Treating 5.5 million MT/y, with 4,000 MT storage in steel tanks and 4,000 MT/h treatment rate.

[5] Treating ≈3 ships/week (described as 40% utilization in AQIS 1993a), or 7 million MT/y.
[6] Treating ≈5 ships/week (described as 70% utilization in AQIS 1993a), or 11.5 million MT/y.

The study concluded that "land-based or port-based [=treatment ship] facilities are more economic and effective than numerous ship-board plants." In these estimates, significant costs were not included in the onshore alternatives which reduced their estimated total cost relative to the shipboard alternative. On the other hand, basing the analysis on the large bulk carriers, which typically discharge the largest volumes of ballast water of the vessels using Australia's ports, greatly favored shipboard treatment[4]; and the onshore alternatives (using granular filtration and UV) would treat ballast water to a substantially higher standard than the shipboard alternative (using only a 50 µm strainer). The estimates are also sensitive to other factors, including the assumed utilization rates for the onshore systems, and the interest rate used to annualize costs.

In another study conducted for the Canadian Coast Guard, Aquatic Sciences (1996) considered onshore treatment alternatives (referred to as "pump off options") for Great Lakes shipping and found them to be "technically feasible" and to "undoubtedly offer the best assurance of prevention of unwanted introductions." The report further found that when installed onshore, "treatment options could have a more practical and enforceable application" than in shipboard installations, and concluded that "ship board treatment of ballast water appears to be logistically, economically, and particularly from the aspect of control, the least attractive method of ballast water treatment." The report estimated that treatment ships could be provided at key ports throughout the Great Lakes to receive discharged ballast water and heat it to >65°C at an annual cost of around $65 million (including annualized capital costs), or alternately a single treatment ship could operate at a site en route to the Great Lakes to treat all incoming ballast water at a capital cost of $20-22 million and an annual operating cost of $2 million. Retrofitting costs to enable ships to discharge their ballast water to treatment ships could exceed $260,000 per ship.[5]

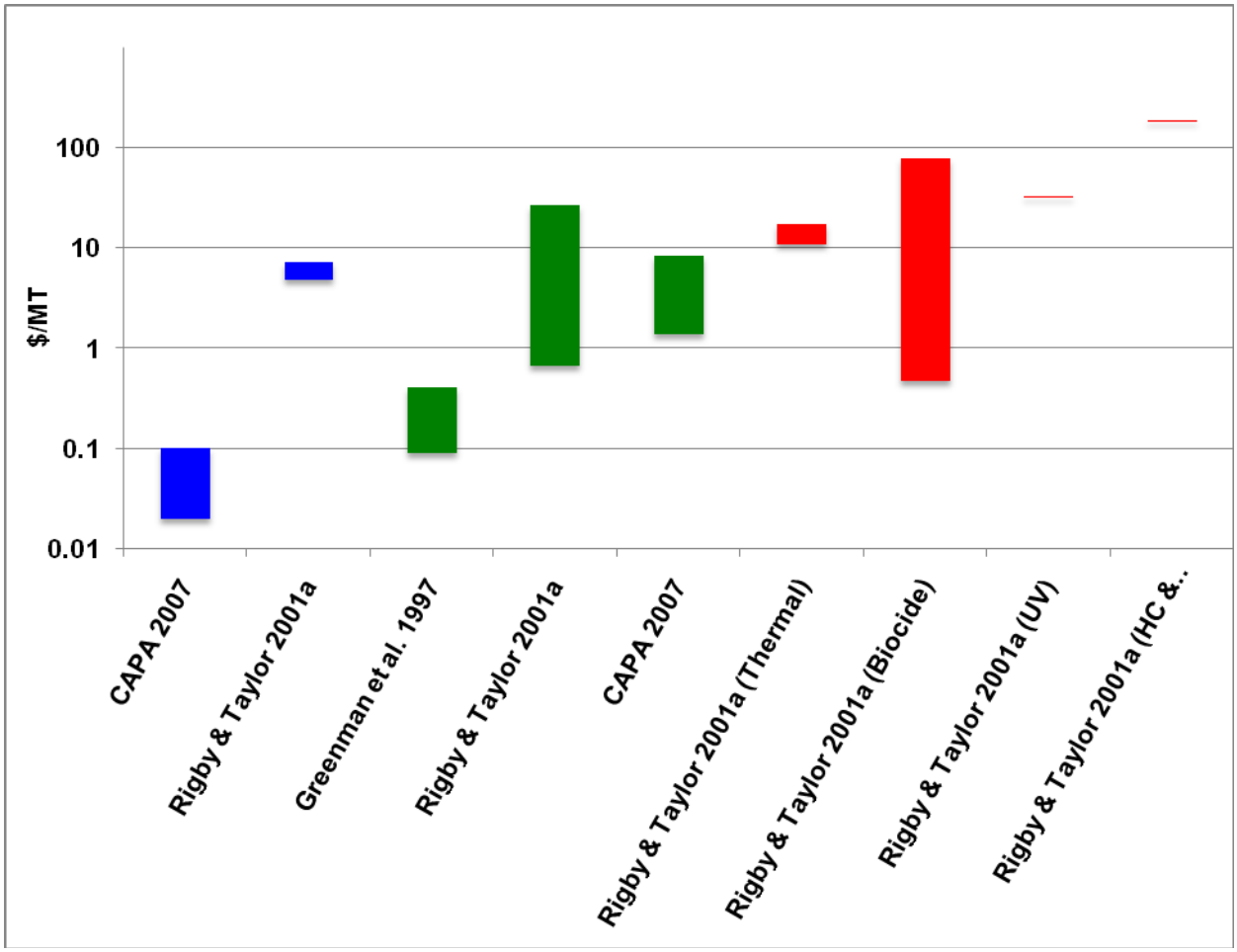
California's State Water Resources Control Board (SWRCB) conducted a qualitative evaluation of onshore treatment and ten shipboard treatment alternatives in terms of effectiveness, safety, and environmental acceptability. Onshore treatment was the only approach to be rated acceptable in all three categories. There were reservations or unresolved questions about the effectiveness of all of the shipboard alternatives, about the safety of eight of the shipboard alternatives, and about the environmental acceptability of nine of the shipboard approaches.

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

[4] That is, with a more realistic mix of ships the estimated costs would be substantially higher for shipboard treatment, but only slightly higher for onshore treatment.
[5] The costs cited in this paragraph were adjusted to June 2010 US dollars as described in Appendix 1.

onshore and shipboard treatment approaches available. In addition, the U.S. Coast Guard compiled a table of cost estimates from different studies for public review and comment (U.S. Coast Guard 2002). Figure VI.A-1 shows all the estimates that were expressed in the table as costs per metric ton or cubic meter of ballast water, and thus in a form that can be compared. In these estimates, onshore treatment is generally more expensive than ballast water exchange and less expensive than shipboard treatment, though there is considerable overlap.

Figure VI.A-1. Cost estimates listed in U.S. Coast Guard (2002). The Coast Guard converted Australian estimates to U.S. dollars at the Oct. 16, 2001 exchange rate, but did not adjust estimates for inflation. Cost estimates for ballast water exchange are in blue, for onshore treatment in green, and for shipboard treatment in red.



The other comparisons of onshore and shipboard treatment in the literature consist of lists or

brief discussions of their relative merits. These reports variously conclude that onshore treatment is probably a superior or probably an inferior option compared to shipboard treatment, or that onshore treatment is suitable for a particular part of the cargo fleet (Table VI.A-1), but none provide any significant analysis or data to support these conclusions.

Two studies (in addition to AQIS (1993a) and Aquatic Sciences (1996), discussed above) provide conceptual designs and cost estimates for onshore treatment for specific regions. CAPA (2000) is an EPA-funded study conducted for the California Association of Port Authorities. This study developed conceptual designs and cost estimates for constructing and operating ballast water treatment plants at each cargo port in California. These plans and estimates include the piping from berths to plants; storage tanks; coagulation, flocculation, filtration and UV disinfection; thickening, dewatering and land-fill disposal of residuals; and discharge of effluent through an outfall pipeline; they did not include land costs, permitting, seismic evaluation, or costs to retrofit vessels to enable them to discharge ballast water to an onshore facility. The study concluded that onshore treatment would be technically and operationally feasible, though there could be delays to some vessels in some circumstances. The estimated costs are shown in Table VI.A-3.

Table VI.A-3. Cost estimates for onshore treatment in California (CAPA 2000). The figures have been adjusted to June 2010 US dollars as described in Appendix 1.

	— — — Capital Costs — — —					
Port	**Pipes**	**Storage Tanks**	**Treatment Plant**	**Outfall**	**Annual O&M**	**Annualized Costs**
Hueneme [1]	1,325,069	69,014	0	125,480	0	50,652
Humboldt Bay	15,900,826	5,019,200	2,234,799	125,480	187,969	963,979
Long Beach	35,909,364	6,399,480	2,786,158	125,480	280,390	1,787,739
Los Angeles	33,921,761	25,597,920	2,786,158	125,480	280,390	2,361,434
Oakland	19,876,032	4,768,240	2,234,799	125,480	187,969	1,088,121
Redwood City	1,987,603	5,395,640	2,047,206	125,480	178,684	497,215
Richmond	7,287,878	4,266,320	2,047,206	125,480	178,684	636,246
Sacramento	1,722,589	6,023,040	2,047,206	125,480	178,684	509,294
San Diego	11,660,605	3,889,880	2,047,206	125,480	178,684	769,456
San Francisco	10,600,550	7,905,240	2,234,799	125,480	187,969	883,505
Stockton	6,757,851	6,901,400	2,047,206	125,480	178,684	706,415
California	146,950,130	76,235,374	22,512,743	1,380,280	2,018,105	10,254,056

[1] CAPA (2000) found that the volume of ballast discharged at Port Hueneme (<2 MT/d) is so small that constructing the type of treatment plant that was designed for the other ports

made no sense, and instead stated that the ballast water "could potentially be discharged to the sewer, reballasted to an outgoing ship, taken to another port for treatment,...transported by a separate vessel for discharge at sea" or batch treated with chlorine. The report estimated piping, storage and outfall costs but did not estimate treatment plant costs for this site.

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

- 100-µm filtration followed by UV treatment;
- ozonation;
- 500-µm filtration followed by membrane filtration to remove particles >0.1 µm;
- filtration[6] followed by hydrodynamic cavitation.

These were each analyzed along with two systems for transferring and storing the discharged ballast water: discharge at berths into pipes that carry the water to on-land storage tanks and a treatment plant; and discharge to a barge that stores the water and carries it to an on-land treatment plant. Design criteria assumed 85 vessel arrivals during the eight months that the St. Lawrence Seaway is open each year, and a system capable of receiving ballast water at 680 MT/h, with storage capacity of 1,900 MT, and treatment at 80 MT/h. Estimated costs are shown in Table VI.A-4. The report concluded that all four treatment systems and both transport/storage systems are feasible, with UV treatment and hydrodynamic cavitation having the most promise for treating viruses (Brown and Caldwell 2007). The second report (Brown and Caldwell 2008) developed a design and cost estimate for retrofitting a barge to serve as a treatment ship, which would collect, store and treat ballast water. The treatment system included a cloth media disk filter with a nominal pore size of 10 µm, and UV treatment at an estimated minimum dose of 30 mJ/cm^2. The design criteria for this analysis required the capacity to receive ballast discharges at 2,300 MT/h, storage of 10,000 MT, and treatment at 230 MT/h, thus around 3 times the flow rates and 5 times the storage required in the first report. The cost estimates for the eight on-land treatment alternatives analyzed in the first report, adjusted to meet the more demanding design criteria used in the second report, plus the cost estimates for the treatment ship in the second report, are shown in Table VI.A-5.

Table VI.A-4. Cost estimates for onshore treatment for oceangoing ships at the Port of Milwaukee (Brown and Caldwell 2007). The figures have been adjusted to June 2010 US

[6] Described as "fine filtration" without further definition; elsewhere in the report this term refers to 100-µm or 500µm filtration.

dollars as described in Appendix 1.

	— — Capital Costs — —				
Treatment (Transport) [1]	**Pipes [2]**	**Storage**	**Treatment**	**Annual O&M**	**Annualized Costs**
100-µm filter & UV (pipes)	2,973,120	1,251,840	584,192	13,986	399,885
Ozone (pipes)	2,973,120	1,251,840	834,560	9,806	415,795
0.1-µm membrane filter (pipes)	2,973,120	1,251,840	1,043,200	19,917	442,648
Hydrodynamic cavitation (pipes)	2,973,120	1,251,840	2,608,000	20,864	569,158
100-µm filter & UV (barge) [3]	260,800	521,600	584,192	386,409	496,068
Ozone (barge) [3]	260,800	521,600	834,560	382,228	511,978
0.1-µm membrane filter (barge) [3]	260,800	521,600	1,043,200	392,340	538,830
Hydrodynamic cavitation (barge) [3]	260,800	521,600	2,608,000	393,286	665,341

[1] Design criteria are: maximum ballast discharge of 680 MT/h, storage of 1,900 MT, and treatment rate of 80 MT/h. “Pipes” refers to discharge of ballast water into a pipe system connecting to the treatment plant; “barge” refers to discharge to a barge to transport the ballast water to the treatment plant.

[2] Includes collection pumps and a lift/screening station.

[3] "Storage" refers to barge purchase and modification costs for use as transfer and storage vessel, exclusive of treatment system.

Table VI.A-5. Cost estimates for onshore treatment for oceangoing ships at the Port of

Milwaukee (Brown and Caldwell 2007, 2008). The figures for the eight alternatives analyzed in Brown and Caldwell (2007) have been adjusted to meet the design criteria of Brown and Caldwell (2008) as described in Appendix 2. All figures have been adjusted to June 2010 US dollars as described in Appendix 1.

	— — Capital Costs — —				
Treatment (Transport) [1]	**Pipes [2]**	**Storage**	**Treatment**	**Annual O&M**	**Annualized Costs**
100-µm filter & UV (pipes)	5,111,705	3,546,880	1,168,384	42,771	831,313
Ozone (pipes)	5,111,705	3,546,880	1,669,120	9,806	838,528
0.1-µm membrane filter (pipes)	5,111,705	3,546,880	2,086,400	19,917	882,123
Hydrodynamic cavitation (pipes)	5,111,705	3,546,880	5,007,360	20,864	1,117,455
100-µm filter & UV (barge) [3]	521,600	1,043,200	1,168,384	386,409	605,727
Ozone (barge) [3]	521,600	1,043,200	1,669,120	382,228	641,727
0.1-µm membrane filter (barge) [3]	521,600	1,043,200	2,086,400	392,340	685,321
Hydrodynamic cavitation (barge) [3]	521,600	1,043,200	5,007,360	393,286	920,654
10-µm filter & UV (treatment ship) [3]	0	2,695,184	808,854	518,914	800,087

[1] Design criteria are: maximum ballast discharge of 2,300 MT/h, storage of 10,000 MT, and treatment rate of 230 MT/h. “Pipes” refers to discharge of ballast water into a pipe system connecting to the treatment plant; “barge” refers to discharge to a barge to transport the ballast water to the treatment plant.

[2] Includes collection pumps and a lift/screening station.

[3] "Storage" refers to barge purchase and modification costs for use as transfer and storage vessel or as treatment ship, exclusive of treatment system.

Besides the need for facilities to receive and transport ballast water from ships, store it and treat it, ships must be modified so they can safely and rapidly discharge ballast water to onshore facilities. There have been several estimates of the costs of these retrofits (Table VI.A-6), which require modifications in a ship’s pipe system and may require the installation of larger ballast

pumps (in order to raise the water to deck level, and/or to discharge it quickly enough). These costs may vary widely between different types and sizes of ships, with the costs for container ships ranging from around $15,000 to $540,000 (Pollutech 1992; Glosten 2002), for bulkers ranging from around $15,000 to $500,000 (Pollutech 1992; CAPA 2000), and for tankers from considerably less than $140,000 to around $2.3 million (Victoria ENRC 1997; Glosten 2002) (Fig. VI.A-2). Most of these estimates specifically included costs for replacing existing pumps with more powerful pumps (AQIS 1993a; Aquatic Sciences 1996; Dames & Moore 1998; CAPA 2000; Glosten 2002[7]). The estimated cost to outfit a new ship would be less than the cost to retrofit a comparable existing ship (AQIS 1993b; OTHER CITES?), perhaps by as much as an order of magnitude (CAPA 2000).

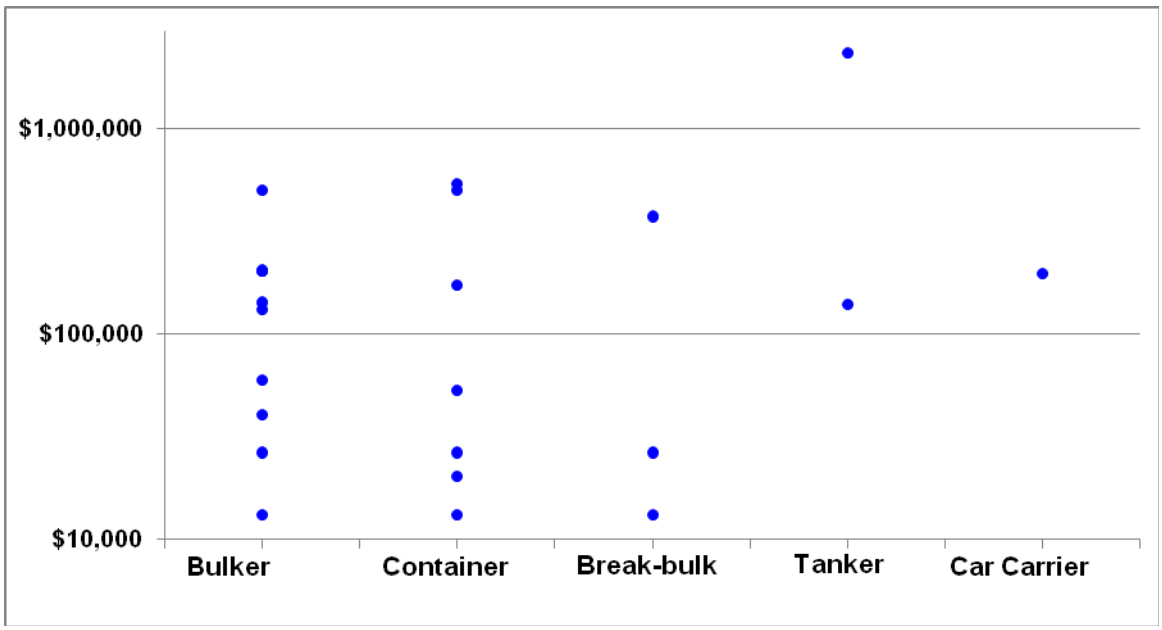
Table VI.A-6. Cost estimates for retrofitting ships to discharge ballast water to a treatment facility. The figures have been adjusted to June 2010 US dollars as described in Appendix 1. In the parentheses following the ship type, length is given in feet, size in deadweight tons (DWT), ballast water capacity in metric tons (MT), and maximum ballast discharge rate in metric tons per hour (MT/h), if stated.

Ship Type	Capital Cost	Report
Great Lakes bulker, break-bulk or container	$13,233–26,465	Pollutech 1992
Small container	$20,408	AQIS 1993a
Large bulker (140,000 DWT; 45,000 MT; 4,000 MT/h)	$204,084	AQIS 1993a
Great Lakes bulker	$40,352–201,758	Aquatic Sciences 1996
Handysize bulker (520'; 22,000 DWT)	$142,340	Victoria ENRC 1997
Container	$53,196-172,887	Dames & Moore 1998 [1]
Container or bulker (1,000 MT/h)	$501,920	CAPA 2000
Tanker (869'; 123,000 DWT; 75,850 MT; 6,400 MT/h)	$2,328,607	Glosten 2002
Bulker (735'; 67,550 DWT; 35,000 MT; 2,600 MT/h)	$131,316	Glosten 2002
Break-bulk (644'; 40,300 DWT; 26,850 MT; 3,000 MT/h)	$373,394	Glosten 2002

[7] Brown and Caldwell (2008) found, based on pump and pipe system curves (dynamic head vs. flow), that the small and large Great Lakes bulk carriers they analyzed would not need larger ballast pumps—that is, with their existing pumps the ships could fully deballast while at berth during the time it takes to load cargo.

Container (906'; 65,480 DWT; 19,670 MT; 2,000 MT/h)	$539,539	Glosten 2002
Car carrier (570'; 13,847 DWT; 6,600 MT; 550 MT/h)	$197,773	Glosten 2002
Bulker (469'; 5,700 MT; 570 MT/h)	$59,694	Brown and Caldwell 2008
Bulker (722'; 18,000 MT; 2,300 MT/h)	$202,960	Brown and Caldwell 2008
[1] Estimate developed by the Pacific Merchant Shipping Association.		

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



Several of these reports provide little or no supporting data or explanation for the cost estimates (Pollutech 1992; AQIS 1993a; Aquatic Sciences 1996; Dames & Moore 1998). Victoria ENRC (1997) provided a materials list for a bulk carrier, and noted that a tanker "with its ballast lines running on deck would have a considerable lower installation cost." CAPA (2000) provided a cost-breakdown for modifying a bulk carrier, and stated that modifying a tanker would generally cost more.

Glosten (2002) and Brown and Caldwell (2008) provided the most recent and most detailed estimates. Glosten (2002) estimated ship modification costs for ballast water transfer systems on five ships representing common types of vessels calling at Puget Sound ports (Table (b)-6). These systems were designed to "allow ballast transfer with minimal disruption to current operations," including sizing them to allow vessels to deballast completely at berth during the time needed to complete cargo loading, thereby eliminating the need to start deballasting before arriving at berth. To represent each vessel category, the authors selected ships that "had ballast systems with capacities on the upper end of vessels that call on Puget Sound to attempt to establish an upper-bound on retrofitting costs." In addition, in selecting pipe sizing and other design elements, "every attempt was made to capture an upper bound on the modification costs associated with each vessel type surveyed." This included the installation of "a completely new piping system to provide the ability to fill and empty each ballast tank separately." Notably, this new piping system was included even though it is not needed on crude oil tankers, the type of tanker analyzed (which produced by far the highest cost estimate in the study), where "a simpler, lower-cost solution" exists, because it might be needed on some other ships (product tankers) in the same general category.[8] The transfer systems were also designed to allow ballast water transfer in either direction between a ship and an onshore facility (either onto or off a ship),[9] which in some cases may raise the cost over what is needed only to discharge ballast water to onshore facilities.

In addition to estimating the costs of treatment in an onshore facility, Brown and Caldwell (2008) provided analyses, conceptual designs, schematic drawings and cost estimates for modifying two sizes of ocean-going bulk carriers serving the Great Lakes, based a smaller, actual ship and a larger hypothetical ship (Table (b)-6). These designs were sized to allow the ship to initiate and complete deballasting at berth during cargo loading.

VI.B. Advantages of Onshore Treatment Compared to Shipboard Treatment

Onshore ballast water treatment systems have numerous inherent advantages relative to shipboard treatment, which have cited in various studies.

1. Onshore treatment requires fewer treatment plants and less total treatment capacity. For shipboard treatment, a treatment plant must be installed on each ship. In nearly all cases these treat ballast water either during ballast uptake, during discharge, or both (Table VI.B-1),[10] and

[8] This is consistent with the study's stated aim, to quantify "the capital cost required to provide the maximum capability in a ballast transfer system, to represent a maximum capital investment" for each vessel category (Glosten 2002).
[9] The ability to move ballast water onto a ship from an onshore service was included to accomodate the possibility of loading "clean" ballast, an approach that is not considered to be onshore treatment in this report.
[10] Physical separation processes (filtration, electro-mechanical separation or hydrocyclones) all produce an untreated waste stream (backwash from filters or underflow from hydrocyclones), which essentially requires that these processes be conducted during ballast uptake so this untreated water can be

must be large enough to accommodate the ships' maximum ballast pumping rates (ABS 2010), which are often in the 1,000-2,000 MT/h range, and can be as high as 20,000 MT/h (Table VI.B-2). The total treatment capacity needed is thus nearly equal to the sum of the maximum ballast uptake or discharge rates of all the ships. In contrast, in onshore treatment on plant can serve a large number of ships, and because all ships do not arrive and discharge ballast water simultaneously in a region, the inherent treatment capacity needed, even without any storage, will always be much less than the sum of the maximum ballast discharge rates of the ships. However, some ballast water storage will always or nearly always be included in an onshore plant, and depending on the relative costs of storage and treatment, could be sized to reduce the needed treatment capacity to the average ballast water discharge rate.

Table VI.B-1. Percentage of shipboard ballast water treatment systems that treat during ballast uptake, ballast discharge, or both. Treatment phase and commercial availability (through 2009) from Lloyd's Register 2010, Tables 5 & 6; type approval (though February 2010) from ABS 2010, Table 7.

Treatment Phase	All treatment systems (n=41)	Commercially available systems (n=21)	Type-approved systems (n=10)
Uptake only	37%	48%	50%
Discharge only	7%	4%	0%
Both	51%	48%	50%
Uptake or discharge	95%	100%	100%

Table VI.B-2. Ships' typical maximum ballast water pumping rates. The maximum pumping rate is the summed rate of all ballast pumps that can operate simultaneously.

discharged back to the source waters (Lloyd's Register 2010). UV is generally applied immmediately after this initial particle-removal process, because it is less effective if particles are present in the water, and in some treatment systems is also applied, without further filtration/particle removal, during discharge (ABS 2010). Biocides are generally injected during uptake, to promote mixing and maximize contact time. Chlorine is generally injected (or created by electro-chlorination) immediately after particle removal both to enhance its effectiveness and to maximize contact time, and chlorine neutralization (which occurs nearly instantaneously) is then conducted during discharge. In all of these cases, which cover most of the treatment processes being used to address ballast water, the system must be sized to treat the maximum ballast flow rate on uptake or discharge. Deoxygenation appears to be the only treatment approach that is, in some systems, applied only during the voyage and not during either uptake or discharge (Lloyd's Register 2010; ABS 2010).

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

Table VI.B-3 compares the estimated number of individual treatment plants and the total treatment capacity that would need to be constructed or installed for onshore vs. shipboard treatment approaches for the Port of Milwaukee, Australia, California and the United States, over a 20-year (Milwaukee) or 30-year (the other sites) project life. The estimated onshore capacities for the first three sites are based on adjusted estimates from the available studies (Brown and Caldwell 2008, AQIS 1993a and CAPA 2000, respectively), and the U.S. onshore estimate is based on the California estimate adjusted to the total amount of ballast water discharged in the U.S. These estimates are explained in detail in Appendix 3.

Table VI.B-3. Treatment plant and capacity estimates for the Port of Milwaukee, Australia, California and the United States. Assumptions and methods are described in Appendix 3.

	Number of Treatment Plants		Total Capacity of Treatment Plants (MT/h)	
Site	**Onshore**	**Shipboard**	**Onshore**	**Shipboard**
Milwaukee	1	19	230	22,800
Australia	23	2,160	34,940	1,188,000
California	16	13,115	1,814	18,883,140
United States	314	86,400	35,549	124,070,400

Based on these estimates, the number of treatment plants that would be needed for shipboard treatment over the period of the estimate is between nearly 20 times and over 800 times the number needed for onshore treatment, depending on the region. For the U.S. as a whole, shipboard treatment would require the installation of nearly 300 times as many treatment plants as onshore treatment. The treatment capacity needed for shipboard treatment is between >30 times and >10,000 times the capacity needed for onshore treatment, depending on the region, and for the U.S. as a whole it is about 3,500 times what is needed for onshore treatment.

2. Onshore treatment avoids constraints that exist with shipboard treatment. Major constraints include limited space (Pollutech 1992; AQIS 1993a; Aquatic Sciences 1996; Cohen 1998; Albert & Everett 2010), limited power (Cohen 1998), limited time, and an unstable platform.

3. A greater variety of treatment methods is available onshore. Any treatment method used in a shipboard application can be used onshore; however, there are treatment methods available for use onshore that cannot practically be used in shipboard application because of space, stability or safety constraints. These include several common and relatively inexpensive water or wastewater treatment processes such as settling tanks, flotation processes and granular filtration (AQIS 1993a; Gauthier & Steel 1996; Victoria ENRC 1997; Cohen 1998; Reeves 1999; Cohen & Foster 2000; California SWRCB 2002) and the use of chlorine gas for disinfection (Cohen & Foster 2000), as well as microfiltration, ultrafiltration and reverse osmosis processes (AQIS 1993a).

4. Onshore treatment plants can be run by trained wastewater treatment personnel. Shipboard treatment plants will likely be operated by common ship personnel, with operation of the ballast treatment process added to their existing duties, with the likelihood that these systems will be maintained or operated with suboptimal effectiveness (Pollutech 1992; AQIS 1993a; Aquatic Sciences 1996; Reeves 1998. Operation of treatment systems by better trained personnel with result in superior performance (Cohen 1998; California SWRCB 2002; Brown & Caldwell 2007); maintenance and repair work are also more likely to be done effectively and efficiently,

and needed replacement parts obtained more quickly, in onshore plants (AQIS 1993a; Aquatic Sciences 1996; Cohen 1998; Cohen & Foster 2000).

5. Onshore treatment is more reliable. Extra capacity and redundancy can be included in an onshore plant, but may be impractical in a shipboard plant due to space and other constraints.

6. Onshore treatment is more effective.

7. Onshore treatment is safer. Shipboard treatment entails restricted access and working space and difficult and potentially hazardous working conditions at sea (AQIS 1993a; Cohen 1998; Cohen & Foster 2000). For treatment processes that involve the storage and use of biocides or other hazardous chemicals, in onshore applications there is less risk of harm to personnel (Cohen 1998; Reeves 1998; Cohen & Foster 2000) and less risk of accidental discharge to the environment (Pollutech 1992; AQIS 1993a).

8. Onshore treatment is more adaptable.

9. Compliance monitoring and regulation would be easier, cheaper and more effective onshore. The amount and cost of regulatory monitoring and enforcement needed to achieve a given level of compliance is expected to be much less, for a relatively small number of onshore, domestic treatment plants compared to a much larger number of mobile, transient, sometimes foreign-owned treatment plants, which are accessible only when in port for (usually) short periods of time (AQIS 1993a; Ogilvie 1995; Aquatic Sciences 1996; Cohen 1998; Dames & Moore 1999; Oemke 1999; Cohen & Foster 2000; California SWRCB 2002; Brown and Caldwell 2008).

VI.C. Operational Issues Potentially Restricting the Use of Onshore Treatment

VI.D. Cost of Onshore vs. Shipboard Treatment

VI.E. Potential Effectiveness of Onshore Treatment

VII. Combined Approaches

It may be possible to meet more stringent discharge standards, or otherwise reduce the risk of invasions from ballast water discharges, by combining the approaches discussed in Section V with either shipboard or onshore treatment.

References

ABS. 2010. Ballast Water Treatment Advisory. American Bureau of Shipping, Houston, TX.

Albert, R., R. Everett, J. Lishman and D. Smith. 2010. Availability and Efficacy of Ballast Water Treatment Technology: Background and Issue Paper. U.S. Environmental Protection Agency, Washington D.C. 77 pages.

Albert, R. and R. Everett. 2010. Capabilities of shipboard ballast water treatment technology. Presentation to EPA's Science Advisory Board, July 29, 2010.

AQIS. 1992. Controls on the Discharge of Ballast Water and Sediment from Ships Entering Australia from Overseas. Australian Quarantine and Inspection Service, Notice (Barrier Co-ordination) 92/2.

AQIS. 1993a. Ballast Water Treatment for the Removal of Marine Organisms. Prepared by Gutheridge, Haskins and Davey Pty Ltd. Ballast Water Research Series Report No. 1, Australian Quarantine and Inspection Service, Canberra. 106 pages.

AQIS. 1993b. Ballast Water Management Study. Prepared by Thompson Clarke Shipping Pty Ltd. Ballast Water Research Series Report No. 4, Australian Quarantine and Inspection Service, Canberra. 254 pages.

Aquatic Sciences. 1996. Examination of Aquatic Nuisance Species Introductions to the Great Lakes through Commercial Shipping Ballast Water and Assessment of Control Options Phase II. Final Report. A report for the Canadian Coast Guard. Aquatic Sciences Inc., St. Catharines, Ontario. 60 pages.

Brown & Caldwell. 2007. Port of Milwaukee Onshore Ballast Water Treatment–Feasibility Study Report. Prepared for the Wisconsin Department of Natural Resources. Brown and Caldwell, Milwaukee, WI. 114 pages.

Brown & Caldwell and Bay Engineering. Inc. 2008. Port of Milwaukee Onshore Ballast Water Treatment–Feasibility Study Report. Phase 2. Prepared for the Wisconsin Department of Natural Resources. Brown and Caldwell, Milwaukee, WI. 98 pages.

California SLC. 2009. 2009 Assessment of the Efficacy, Availability and Environmental Impacts of Ballast Water Treatment Systems for Use in California Waters. California State Lands Commission, Sacramento, CA. 180 pages.

California SLC. 2010. Draft 2010 Assessment of the Efficacy, Availability and Environmental Impacts of Ballast Water Treatment Systems for Use in California Waters. California State Lands Commission, Sacramento, CA. 149 pages.

California SWRCB. 2002. Evaluation of Ballast Water Treatment Technology for Control of Nonindigenous Aquatic Organisms. State Water Resources Control Board, California Environmental Protection Agency, Sacramento, CA. 70 pages.

Canada. 2000. Guidelines for the Control of Ballast Water Discharge from Ships in Waters under Canadian Jurisdiction. TP 13617, Canadian Marine Advisory Council, Ottawa.

Canada. 2007. A Guide to Canada's Ballast Water Control and Management Regulations. TP 13617E, Transports Canada, Ottawa.

CAPA. 2000. Feasibility of Onshore Ballast Water Treatment at California Ports. Prepared by URS Corporation/Dames & Moore. California Association of Port Authorities, Sacramento, CA.

Carlton, J. T., Reid, D. M. and H. van Leeuwen. 1995. Shipping Study. The Role of Shipping in the Introduction of Nonindigenous Aquatic Organisms to the Coastal Waters of the United States (other than the Great Lakes) and an Analysis of Control Options. Report No. CG-D-11-95, U. S. Coast Guard, Groton CT and U. S. Dept. of Transportation, Washington DC.

Cohen, A.N. 1998. Ships' Ballast Water and the Introduction of Exotic Organisms into the San Francisco Estuary: Current Status of the Problem and Options for Management. A report for CALFED and the California Urban Water Agencies. San Francisco Estuary Institute, Richmond CA.

Cohen, A.N. and B. Foster. 2000. The regulation of biological pollution: Preventing exotic species invasions from ballast water discharged into California coastal waters. Golden Gate University Law Review 30(4): 787-883.

CSLC. 2009. 2009 Assessment of the Efficacy, Availability and Environmental Impacts of Ballast Water Treatment Systems for Use in California Waters. California State Lands Commission, Sacramento, CA. 180 pages.

CSLC. 2010. 2010 Assessment of the Efficacy, Availability and Environmental Impacts of Ballast Water Treatment Systems for Use in California Waters. California State Lands Commission, Sacramento, CA. 141 pages.

Dames and Moore. 1998. Ballast Water Management Technical Memorandum for the Port of Oakland. Job No. 02801-028-086, November 6, 1998. Dames and Moore, San Francisco, CA.

Dames and Moore. 1999. Phase I Final Report Ballast Water Exchange and Treatment. A Report for the California Association of Port Authorities, Pacific Merchant Shipping Association, Steamship Association of Southern California, and Western States Petroleum Association. Dames and Moore, San Francisco, CA.

Gauthier, D. and D.A. Steel. 1996. A Synopsis of the Situation Regarding the Introduction of Nonindigenous Species by Ship-Transporting Ballast Water in Canada and Selected Countries. Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 2380. Marine Environmental Sciences Division, Department of Fisheries and Oceans, Maurice Lamontagne Institute, Mont-Joli (Quebec), Canada.

Glosten. 2002. Pacific Ballast Water Treatment Pilot Project: Ballast Water Transfer Study: Technical Feasibility with Associated Capital Costs. Prepared for the Port of Seattle, Seattle, WA. File No. 01080. The Glosten Associates, Seattle, WA. 36 pages.

Greenman, D., K. Mullen and S. Parmar. 1997. Ballast Water Treatment Systems: A Feasibility Study. Produced in cooperation with ENS Chris Friese, U.S. Coast Guard Office of Response. Commissioned by the U.S. Coast Guard and Worcester Polytechnic Institute. Submitted to Professor Matthew Ward, Washington, D.C. Project Center, Worcester Polytechnic Institute. ANS Task Force Reports and Publications, December 17, 1997. 59 pages.

Hallegraeff, G.M. and C.J. Bolch. 1992. Transport of diatom and dinoflagellate resting spores in ships' ballast water: implications for plankton biogeography and aquaculture. Journal of Plankton Research 14: 1067-1084.

IMO. 1991. International Guidelines for Preventing the Introduction of Unwanted Aquatic Organisms and Pathogens from Ships' Ballast Water and Sediment Discharges. International Maritime Organization, Marine Environment Protection Committee, Resolution MEPC 50(31), adopted 4 July 1991.

IMO. 1993. Guidelines for Preventing the Introduction of Unwanted Aquatic Organisms and Pathogens from Ships' Ballast Water and Sediment Discharges. International Maritime Organization, Resolution A.774(18), adopted 4 November 1993.

IMO. 1997. Guidelines for the Control and Management of Ships' Ballast Water to Minimize the Transfer of Harmful Aquatic Organisms and Pathogens. International Maritime Organization, 20th Assembly, Resolution A.868(20), adopted 27 November 1997.

IMO. 2004. International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004. International Maritime Organization, International Conference on Ballast Water Management for Ships.

IMO. 2005a. Guidelines tor Ballast Water Management Equivalent Compliance (G3). International Maritime Organization, Marine Environment Protection Committee, Resolution MEPC 123(53), adopted 22 July 2005.

IMO. 2005b. Guidelines for Ballast Water Management and Development of Ballast Water Management Plans (G4). International Maritime Organization, Marine Environment Protection Committee, Resolution MEPC 127(53), adopted 22 July 2005.

IMO. 2006. Guidelines for Ballast Water Reception Facilities (G5). International Maritime Organization, Marine Environment Protection Committee, Resolution MEPC 153(55), adopted 13 October 2006.

Lloyd's Register. 2010. Ballast Water Treatment Technology: Current Status. Lloyd's Register, London.

Miller, A.W., K. Lion, M.S. Minton and G.M. Ruiz. 2007. Status and Trends of Ballast Water Management in the United States. Third Biennial Report of the National Ballast Information Clearinghouse (January 2004 to December 2005). Submitted to the U.S. Coast Guard. National Ballast Information Clearinghouse, Smithsonian Environmental Research Center, Edgewater, MD.

Minton, M.S., Verling, E., Miller, A.W. and Ruiz, G.M. 2005. Reducing propagule supply and coastal invasions via ships: effects of emerging strategies. Frontiers in Ecology and the Environment 3: 304-308.

New Zealand. 1998. Import Health Standard For Ships' Ballast Water From All Countries (Biosecurity Act 1993). New Zealand Ministry of Agriculture and Forestry, Wellington.

New Zealand. 2005. Import Health Standard For Ships' Ballast Water From All Countries. Issued pursuant to Section 22 of the Biosecurity Act 1993. New Zealand Ministry of Agriculture and Forestry, Wellington.

NRC. 1996. Stemming the Tide: Controlling Introductions of Nonindigenous Species by Ships' Ballast Water. Committee on Ships' Ballast Operations, Marine Board, Commission on Engineering and Technical Systems, National Research Council. National Academy Press, Washington, D.C.

NSF. 2003. Engineering Controls for Ballast Water Discharge: Developing Research Needs. Report of a Workshop. April 28-30, 2003, Seattle, WA. Bioengineering & Environmental Systems Division, Engineering Directorate, National Science Foundation.

Oemke, D. 1999. The Treatment of Ships' Ballast Water. EcoPorts Monograph Series No. 18, Ports Corporation of Queensland, Brisbane, Australia. 102 pages.

Parsons, M.G. and M. Kotinis. 2008. Further Development and Optimization of the Ballast-Free Ship Design Concept. Final Report. Great Lakes Maritime Research Institute, University of Wisconsin-Superior and University of Minnesota-Duluth.

Pollutech. 1992. A Review and Evaluation of Ballast Water Management and Treatment Options to Reduce the Potential for the Introduction of Non-native Species to the Great Lakes. Pollutech Environmental, Ltd., Sarnia, Ontario, prepared for the Canadian Coast Guard, Ship Safety Branch, Ottawa.

Reeves, E. 1998. Protection of the Great Lakes from Infection by Exotic Organisms in Ballast Water. Report for Ninth US Coast Guard District, Cleveland OH.

Reeves, E. 1999. Exotic Policy: An IJC White Paper On Policies for the Prevention of the Invasion of the Great Lakes by Exotic Organisms. Documents on Water Law, College of Law, University of Nebraska - Lincoln. 132 pages.

Rigby, G. and A.H. Taylor. 2001a. Ballast Water Treatment to Minimize the Risks of Introducing Nonindigenous Marine Organisms into Australian Ports. Ballast Water Research Series Report No. 13, Australian Government Department of Agriculture, Fisheries, and Forestry, Canberra. 93 pages.

Rigby, G. and A.H. Taylor. 2001b. Ballast water management and treatment options. Transactions of the Institute of Marine Engineers 113(3): 79-99.

Tagg, R. 1999. Ballast Water Management for Containerships: Implications for the Port of Oakland. Report for the Port of Oakland. Herbert Engineering Corp., San Francisco, CA.

Tamburri, M. 2009. Land-Based Evaluations of the Maritime Solutions, Inc. Ballast Water Treatment System. UMCES Technical Report Series: Ref. No. [UMCES]CBL 09-138, Chesapeake Biological Laboratory, Solomons, MD.

US Coast Guard. 1999. Implementation of the National Invasive Species Act of 1996 (NISA). Interim rule. U.S. Federal Register 64(94): 26672-26690 (May 17, 1999).

US Coast Guard. 2001. Implementation of the National Invasive Species Act of 1996 (NISA). Final rule. U.S. Federal Register 66(225): 58381-58393 (November 21, 2001).

US Coast Guard. 2004. Mandatory Ballast Water Management Program for U.S. Waters. U.S. Federal Register 69(144): 44952-44961 (July 28, 2004).

US Coast Guard. 2008. Ballast Water Discharge Standard - Draft Programmatic Environmental Impact Statement. U. S. Coast Guard, Washington, D.C. 218 pages.

US Congress. 1990. Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990. U.S. Congress, Public Law 101-6461, enacted on November 29, 1990.

US Congress. 1996. National Invasive Species Act of 1996. U.S. Congress, Public Law 104-332, enacted on October 26, 1996.

US EPA. 2001. Aquatic Nuisance Species In Ballast Water Discharges: Issues and Options. Draft Report for Public Comment – September 10, 2001. U.S. Environmental Protection Agency Office of Water, Office of Wetlands, Oceans and Watersheds, Office of Wastewater Management, Washington, D.C.

Victoria ENRC. 1997. Report on Ballast Water and Hull Fouling in Victoria. Parliament of Victoria, Environmental and Natural Resources Committee. Victorian Government Printer, Melbourne, Australia.

(f) Appendices

Appendix 1. Cost Estimate Adjustments and Calculation of Annualized Costs

Estimates made in foreign currencies in the original publications were converted into US dollars at the daily average interbank transfer rates reported at http://www.oanda.com/currency/historical-rates on the date of publication or presentation, or on the first day of the month where only the month of publication was given. For the estimates used in this report, these are:

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

Estimates were inflated from the date of original publication, or from the first day of the month where only the month of publication was given, to June 1, 2010 using the calculator at http://inflationdata.com/inflation/Inflation_Calculators/InflationCalculator.asp, which is based on the U.S. Bureau of Labor Statistics' Consumer Price Index for all Urban Consumers (CPI-U).

Capital costs were annualized by assuming an interest rate of 5%, and the following working lifetimes:

New cargo vessel	25 years
Retrofitted cargo vessel	12.5 years
Treatment ship	20 years
On-land treatment plant	30 years

Appendix 2. Adjustment of the Cost Estimates in Brown and Caldwell (2007) to the Design Criteria in Brown and Caldwell (2008)

The design criteria and the ratio between them are as follows:

Design Criterion	2007 Study	2008 Study	Ratio (2008:2007)
Ballast Discharge Rate (gpm)	3,000	10,000	3.33
Storage (gallons)	500,000	2,700,000	5.40
Treatment Rate (gpm)	350	1,000	2.86

Cost estimates made on the basis of the first set of design criteria were modified to reflect the second set of design criteria as follows:

Capital cost of pipes: The cost estimate for pipes from the berths to the treatment plant reflecting the 2008 study's Ballast Discharge Rate was interpolated from the values in Table 4 in Brown and Caldwell (2007). This cost estimate is 1.7 times the estimate in Brown and Caldwell (2007) based on the 2007 study's Ballast Discharge Rate.

Capital cost for on-land storage tanks: This estimate was taken from Table 6 in Brown and Caldwell (2007) for 3 million gallons of storage (2.7 million gallons of storage is required). This cost estimate is 2.8 times the estimate in Brown and Caldwell (2007) based on the 2007 study's Storage requirement.

Capital cost for barge purchase and modification: This was estimated as the cost of two barges, since one barge has a storage capacity of 1,700,000 gallons (Brown and Caldwell 2007 at p. 15) and 2,700,000 gallons of storage is needed. This value is thus double the estimate in Brown and Caldwell (2007) based on the 2007 study's Storage requirement.

Capital cost for collection pumps: The governing criterion is the Ballast Discharge Rate, which is 3.33 times higher in the 2008 study than in the 2007 study. Other capital costs show substantial economies of scale, that is, the ratio of estimated costs is less than the ratio of design criteria, as follows:

Estimated Cost	Governing Criterion	Ratio of Criteria	Ratio of Cost Estimates
Pipes	Ballast Discharge Rate	3.33	1.7
Storage Tanks	Storage	5.40	2.8
Barge	Storage	5.40	2.0

To reflect economies of scale, the estimated cost for collection pumps was increased by 1.7 relative to the estimate in Brown and Caldwell (2007) based on the 2007 study's Ballast Discharge Rate.

Capital cost for lift station: The governing criterion is the Treatment Rate, which is 2.86 times higher in the 2008 study than in the 2007 study. As with the estimated capital cost for collection pumps, in order to reflect economies of scale the estimated cost for the lift station was increased by 1.7 relative to the estimate in Brown and Caldwell (2007) based on the 2007 study's Treatment Rate.

Capital costs for treatment systems: For Filtration & UV, Ozonation, and Membrane Filtration, the governing criterion is the Treatment Rate, which is 2.86 times higher in the 2008 study than in the 2007 study. For these systems, as with other capital costs whose size is governed by flow rates, in order to reflect economies of scale the estimated cost was increased by 1.7 relative to the estimates in Brown and Caldwell (2007) based on the 2007 study's Treatment Rate.

For Hydrodynamic Cavitation, part of the capital cost is to provide additional storage. This part of the cost was estimated from Table 6 in Brown and Caldwell (2007) for 3 million gallons of storage (2.7 million gallons of storage is required). For the remaining part of the capital cost, as with other capital costs whose size is governed by flow rates, in order to reflect economies of scale the estimated cost was increased by 1.7 relative to the estimates in Brown and Caldwell (2007) based on the 2007 study's Treatment Rate.

Barge O&M: These costs are for towing services, which are based on the number of ship arrivals per year. This number did not change between the two studies, so this cost estimate was not changed.

Treatment system O&M: These costs, and equipment replacement costs which are here included under O&M, appear to be based on the total annual volume of ballast water discharged. This does not appear to change between the two studies, so this cost estimate was not changed.

Two sensitivity analyses were conducted to assess the above assumptions. If the capital costs for collection pumps, lift stations and treatment systems are increased proportional to the governing criteria (Ballast Discharge Rate or Treatment Rate) rather than by a factor of 1.7 (i.e. if we assume that there are no economies of scale in the capital costs for these system components), the cost estimates for the various systems increase by 9-19%. If Treatment system O&M costs are increased proportional to the governing criterion (Treatment Rate) rather than not increased, the cost estimates for the various systems increase by 3-6%. The adjustments in the cost estimates thus seem fairly robust relative to these assumptions.

Appendix 3. Estimates of Treatment Plants and Treatment Capacity Needed in Onshore and Shipboard Treatment Approaches for the Port of Milwaukee, Australia, California and the United States.

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

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

<u>Port of Milwaukee</u>

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

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

for the ships that called during the first year, and ignoring other ships. The estimated number of distinct ships, and of treatment plants needed, is thus 19.

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

<u>Australia</u>

Onshore estimate: AQIS (1993a) estimated that Australia's domestic and foreign ballast discharges could be treated with 3 treatment ships and 18 on-land treatment plants located in Australia's major ports, along with 16 barges to transport ballast water collected at smaller ports. Since the estimated working lives are 20 years for a treatment ship and 30 years for an on-land plant, a 30-year period was used for the estimate and the number of treatment ships required increased to 5. This is a conservative adjustment, since the calculated need is for only 4.5 treatment ships. The total treatment capacity of the 18 on-land plants and 5 tretment ships is 34,940 MT/h.

Shipboard estimate: AQIS (1993a, pp. 86, 88) reported that at least 1,000 different ships visit Australian ports each year, discharging 66 million MT of ballast water. If each of these ships discharges its entire typical ballast load into Australian waters once a month, the typical ballast load would be 5,500 MT. Data on Australian ships shows that maximum ballast pumping rates are about 10% of typical ballast loads (AQIS 1993, Table 4.1), thus the average maximum pumping rate for Australian vessels is estimated to be 550 MT/h. Adjusting the ship numbers for the 30-year period by adding only the expected number of replacement ships (and ignoring other ships, a conservative adjustment) yields 2,160 distinct ships requiring 2,160 treatment plants. With an average maximum pumping rate of 550 MT/h, a total treatment capacity of over one million MT/h would need to be installed.

<u>California</u>

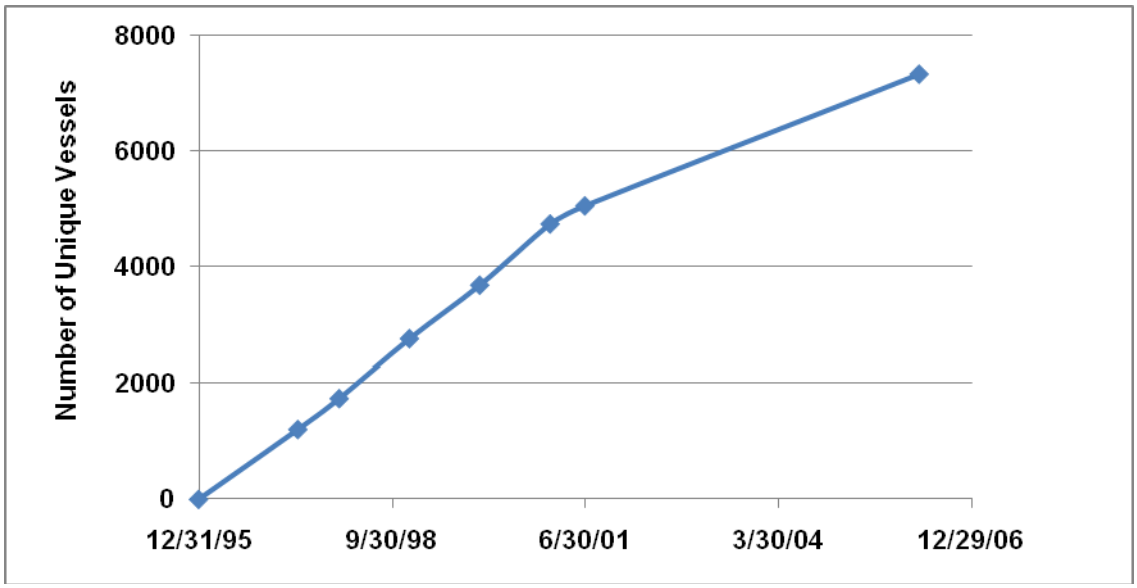
Onshore estimate: CAPA (2000) estimated that 10 on-land treatment plants (one at each of ten ports) with a total treatment capacity of 489 MT/h could treat the ballast water discharged into California waters. However, the port descriptions in this study suggested that it would be more economically efficient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

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

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

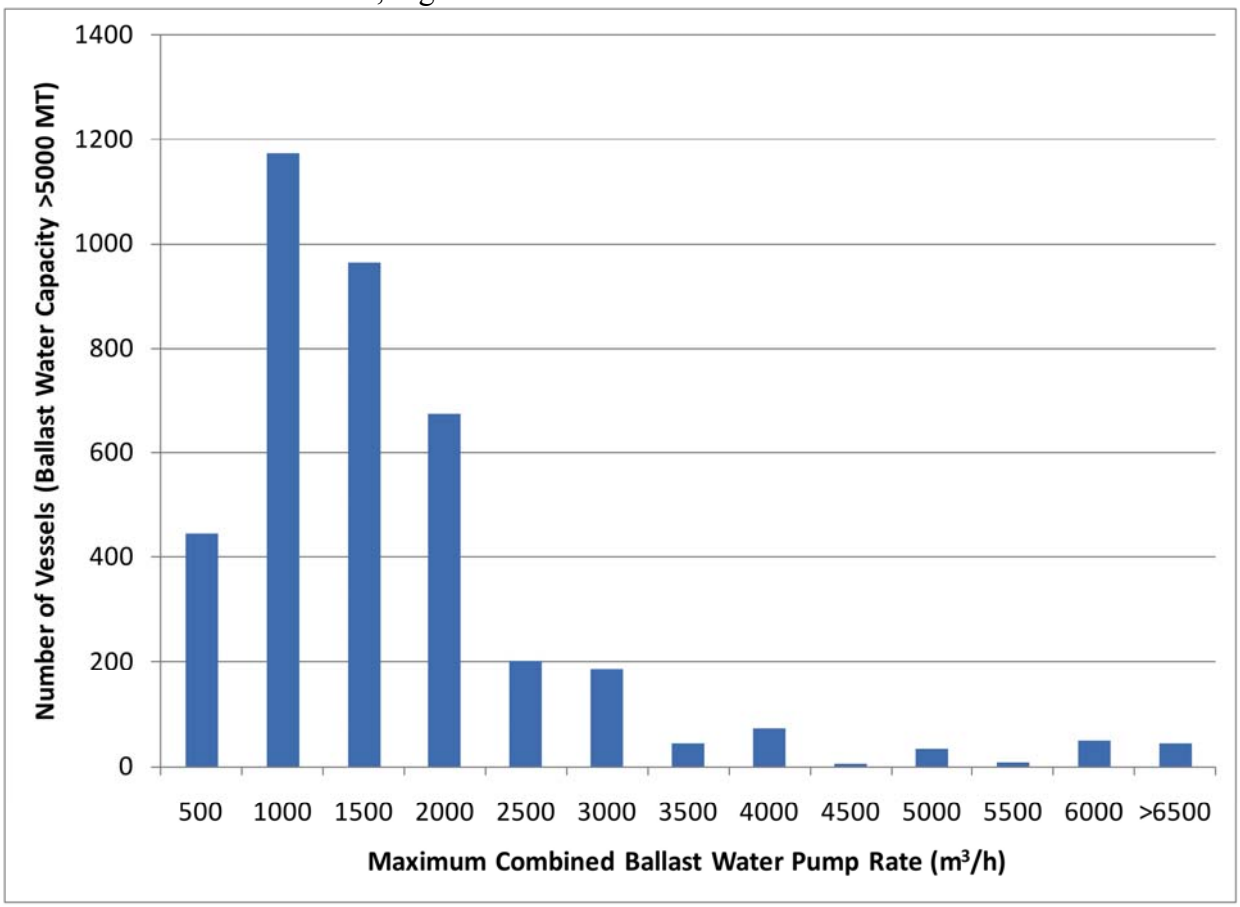
Shipboard estimate, number of treatment plants: Figure 1 below shows the estimated cumulative numbers of distinct ships arriving at California ports since January 1, 2000, based on data provided by the California State Lands Commission or contained in California SLC (2010). It's not clear whether the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

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



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

Figure 2. Maximum ballast water pumping rates of ships that call at California ports.
Source: California SLC 2010, Fig. VI-3.



United States

Onshore estimate: The estimates of the number of onshore treatment plants and the treatment capacity needed in California, derived from estimates in CAPA (2000) and adjusted with more recent ballast discharge data, were mutliplied by the ratio between the estimated total ballast water discharge in the United States (derived from Miller et al. 2007 by the methods described earlier) and the estimated discharge in California. This yielded an estimate of 314 onshore treatment plants needed with a total treatment capacity of 35,549 MT/h.

Shipboard estimate: Approximately 40,000 cargo ships (excluding barges) are estimated to be subject to ballast water discharge requirements in the United States (Albert & Everett 2010). Adjusting the ship numbers for the 30-year period by adding only the expected number of replacement ships (a conservative adjustment) yields 86,400 distinct ships requiring 86,400 treatment plants. No data on pumping rates comparable to the California data in Figure 2 are available for the U.S. as whole. We used the California average maximum pumping rate of 1,436 MT/h, to yield an estimate of total treatment capacity of 124 million MT/h need for shipboard treatment.