EPA SAB Ballast Water Advisory

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

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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.

V.I.A. Studies of Onshore Treatment

[This updated draft contains corrections to Table VI.A-2 and the paragraph preceding the table, needed because of a math error.]

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]

[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).

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

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 & Taylor 2001a,b	Briefly discusses onshore treatment.	Cost, availability, quality control may prevent onshore development, but it might work for tankers that discharge oily ballast to onshore facilities.
US EPA 2001	Briefly mentions onshore treatment.	
California SWRCB 2002	Briefly discusses onshore treatment.	Onshore is an attractive option, at least for some parts of the industry.
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,	Develops designs and estimates costs for onshore treatment at Milwaukee.	Onshore is feasible; treatment ship is cheaper than on-land.

2008		
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 maximum 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 with coagulation, flocculation, granular filtration and UV disinfection at a maximum treatment rate of 830 MT/h, and thickening, dewatering and land-fill disposal of residuals. The cost of land acquisition and the cost of pipes needed to carry ballast water from the berths to the treatment plant were not included. The treatment ship alternative was based on converting a used 12,500 DWT bulk carrier and installing 4,000 MT of storage capacity and a treatment system similar to the on-land system but with a maximum treatment rate of 4,000 MT/h and using pressurized granular filters. The cost estimates, including the cost of retrofitting cargo ships with pipe modifications and possible pump upgrades needed to allow discharge to an onshore treatment plant[4], are summarized in Table VI.A-2. Based on the annualized cost per 1,000 MT of ballast water, treatment in an on-land facility ($221-$336/1,000 MT) is thus about half of the cost of treating it in a shipboard plant ($508/1,000 MT). Treatment in a treatment ship is somewhat more or somewhat less expensive than treatment in a shipboard plant, depending on the utilization rate of the treatment ship (Table VI.A-2).

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

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. The number of ships is calculated as the number of bulk carriers (each discharging 500,000 MT/y) needed to discharge the stated annual treatment volume to the plant.

Treatment System	Number of Ships	Capital Costs: Storage	Capital Costs: Treatment	Ship Retrofit	Operating Cost /1000 MT	Annualized Cost /1000 MT
Shipboard [1]	1	0	2,040,844	0	82	508
On-land [2]	11	3,061,266	6,122,532	2,244,928	92	221
On-land [3]	11	6,122,532	6,122,532	2,244,928	92	255
On-land [4]	11	3,061,266	16,326,752	2,244,928	92	336
Treatment ship [5]	14	8,673,587	12,755,275	2,857,182	422	687
Treatment ship [6]	23	8,673,587	12,755,275	4,693,941	276	450

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

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 (Table 4.1 in AQIS 1993a), greatly favored shipboard treatment[5]; and the onshore alternatives (using granular filtration with coagulation and flocculation followed by UV disinfection) would treat ballast water to a substantially higher standard than the shipboard alternative (using only a 50 µm strainer). 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

[5] That is, if a more realistic mix of ships is used, involving a larger number of ships each discharging a smaller volume of ballast water per year, then the estimated costs would be substantially higher for shipboard treatment, but only slightly higher for onshore treatment. AQIS (1993a, at pp. 86-88) cited estimates of a total of 66,000,000 MT of ballast water discharged into Australian waters each year by at least 1,000 different ships, or an average discharge of less than 66,000 MT/y per ship, compared to the estimate for large bulk carriers of 500,000 MT/y per ship.

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.[6]

California's State Water Resources Control Board (SWRCB 2002) conducted a qualitative evaluation of onshore treatment and ten shipboard treatment alternatives in terms of effectiveness, safety, and environmental acceptability (California SWRCB . 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 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.

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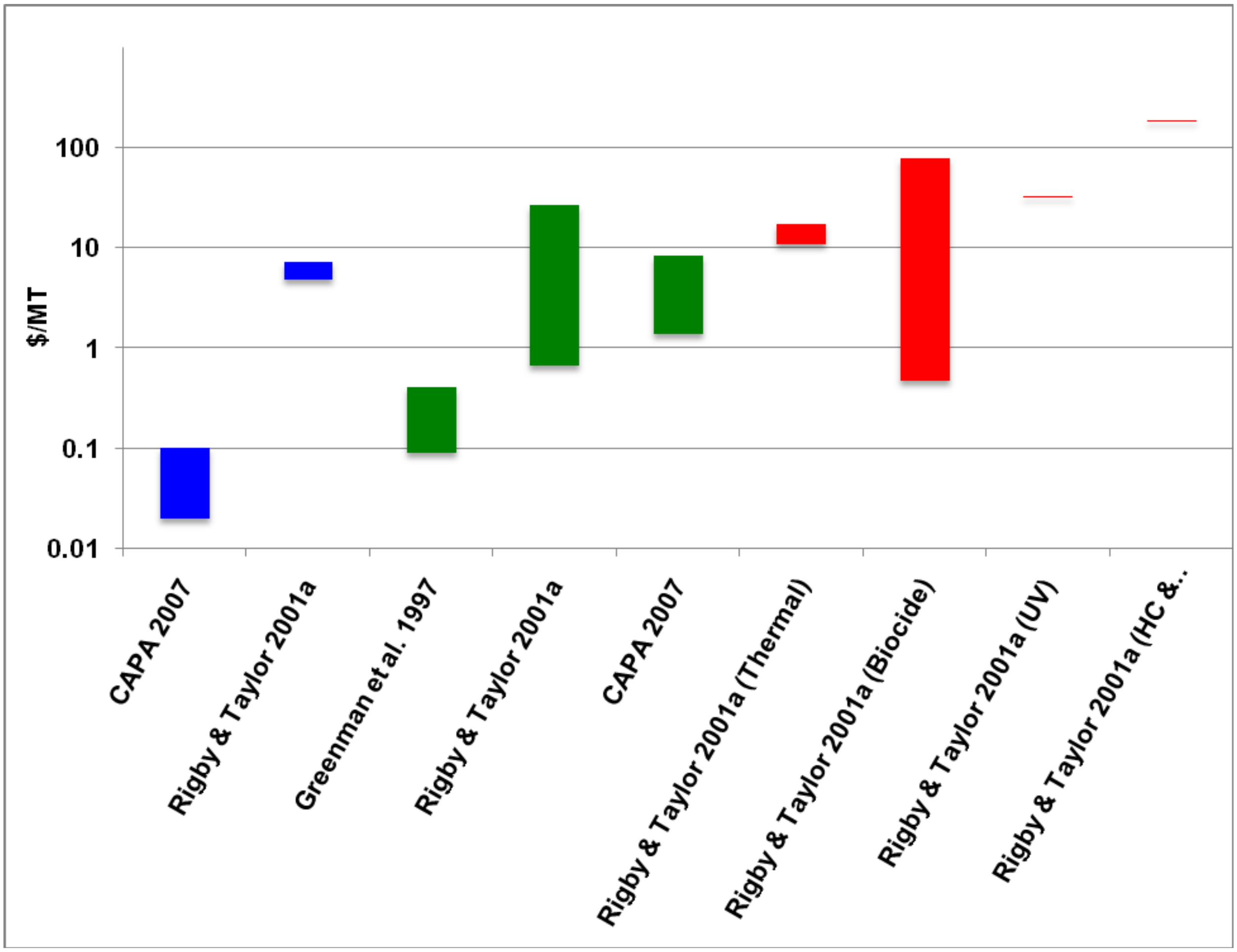
[6] The costs cited in this paragraph were adjusted to June 2010 US dollars as described in Appendix 1.

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[7] 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.

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

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 dollars as described in Appendix 1.

Treatment (Transport) [1]	— — Capital Costs — —			Annual	Annualized
	Pipes [2]	Storage	Treatment	O&M	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.

Treatment (Transport) [1]	— — Capital Costs — —			Annual	Annualized
	Pipes [2]	Storage	Treatment	O&M	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.

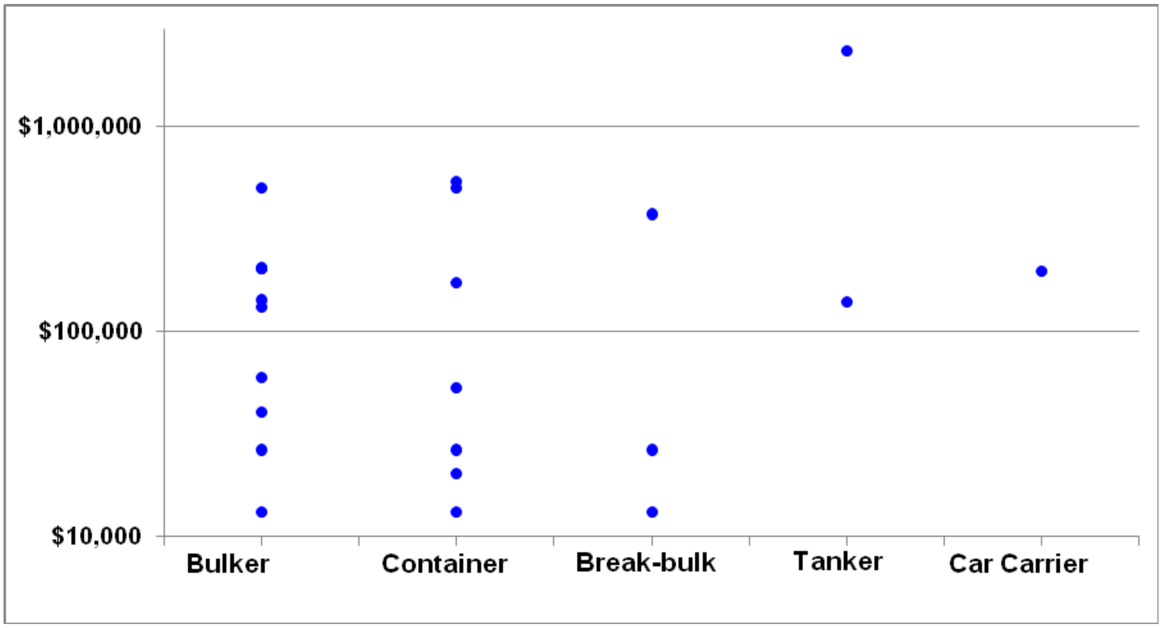
Besides the need for facilities to receive and transport ballast water from ships, store it and treat it, ships must be modified so they can safely and rapidly discharge ballast water to onshore facilities. There have been several estimates of the costs of these retrofits (Table VI.A-6), which require 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[8]). The estimated cost to outfit a new ship would be less than the cost to retrofit a comparable existing ship (AQIS 1993b), perhaps by as much as an order of magnitude (CAPA 2000).

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
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.		

[8] 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.

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.[9] 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),[10] 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

[Much of this section has been updated, including expanding and completing the subparts 2-9].

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 ballast discharge, or both (Table VI.B-1),[11] and must be large enough to accommodate the ship's maximum ballast pumping rate (ABS 2010). This is assumed to be equal to a ship's total ballast pump capacity, which is 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 ballast pump capacities of all the ships. In contrast, in onshore treatment one plant can serve a large number of ships, and because all ships

[9] 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).

[10] 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.

[11] 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 discharged back to the source waters (Cohen & Foster 2000; California SLC 2010; 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).

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 (e.g. see AQIS 1993a; Ogilvie 1995; CAPA 2000; Brown and Caldwell 2007, 2008).

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' total ballast pump capacities. The total ballast pump capacity is the summed capacities of all ballast pumps that can operate simultaneously.

Vessel Type	Typical Total Ballast Pump Capacity (MT/h)	Reference
Containerships	250-750	ABS 2010
Australian Containerships	500-2,000	AQIS 1993a
Containerships	1,100	Rigby & Taylor 2001b
Containerships	1,000-2,000	NRC 1996
Japan-Oregon Woodchip Carriers	780-975	Carlton et al. 1995
Australian Woodchip Carriers	1,000-1,500	AQIS 1993a
Bulk Carriers	1,300-3,000	ABS 2010
Australian Bulk Carriers	1,000-6,000	AQIS 1993a
Capesize Bulk Carriers	6,000	Rigby & Taylor 2001b
Bulk Carriers	2,000-10,000	Reeves 1999
Bulk Carriers, Ore Carriers	5,000-10,000	NRC 1996
Largest Bulk Carriers	to >20,000	AQIS 199a
Australian Tankers	750-3,000	AQIS 1993a
Tankers	1,100-5,800	ABS 2010
LNG Tanker	6,000	Rigby & Taylor 2001b

Tankers	5,000-20,000	NRC 1996; Reeves 1999
Largest Tankers	to >20,000	AQIS 199a
New Zealand ships	1,000-1,500	Ogilvie 1999
Great Lakes ships	550-3,500	Brown and Caldwell 2008
Great Lakes ships	400-5,000	Pollutech 1992
Great Lakes ships	2,000-5,900	Aquatic Sciences 1996
Largest vessels	15,000-20,000	NRC 1996

Table 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; NRC 1996; Cohen 1998; California SLC 2010; Albert & Everett 2010), limited power (NRC 1996; Cohen 1998; California SLC 2010), limited time (NRC 1996; Oemke 1999), and an unstable platform (AQIS 1993a; Cohen 1998; Reeves 1999). Installation plans for shipboard treatment plants generally call for situating them within the ship's engine room, where ballast pumps are usually located (NRC 1996). Aquatic Science (1996) noted that "modern ship design tends toward the reduction of machinery space to maximize cargo capacity, with the result that many modern engine rooms are cramped, allowing only sufficient space for necessary maintenance." Similarly, the National Research Council (1996) noted that "ships are built to carry maximum cargo, [so] non-earning space such as engine rooms...is reduced to a minimum. In particular, engine rooms tend to have very limited space for additional equipment, although the most convenient location for a treatment facility would be in or adjacent to the engine room in which the ballast pumps are located." While it may be possible to expand treatment systems into adjacent or nearby cargo spaces, this involves a costly "double-hit": in addition to the direct costs of the equipment and its installation including piping and bulkhead penetrations to connect back into the engine room, the reduction in cargo capacity reduces revenues.

AQIS (1993a) noted general concerns about restricted access and working space around shipboard treatment equipment. Pollutech (1992) noted that many of the treatment options being considered "could be more easily incorporated into [an onshore] facility in comparison to being fitted into a vessel." The National Research Council (1996), Oemke (1999) and Rigby & Taylor (2001b) noted that heat treatment may not work on short trips, and the same may be true for biocide treatments that require significant contact time in ballast tanks. The motion of a ship makes it difficult and costly to employ granular filtration methods, requiring the use of pressurized containers (AQIS 1993a); Gauthier & Steel (1996) and the National Research Council (1996) concluded that even with pressurized containers, space limitations would make this approach impractical.Engine vibrations and ship motions in rough seas (Welschmeyer 2005; California SLC 2010), concerns about corrosion (Carlton et al. 1995; NRC 1996; Cohen 1998) and hazardous working conditions at sea (NRC 1996; Cohen 1998) may also constrain the types of treatment processes or treatment equipment that can be used on ships, or pose difficulties that require additional costs or effort to resolve.

3. A greater variety of treatment methods is available onshore. Any treatment method used on ships can be used onshore; however, there are treatment methods available for use onshore that cannot practically be used on ships 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[12] (AQIS 1993a; Gauthier & Steel 1996; NRC 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; California SLC 2010). Settling tanks and flotation processes require a steady free surface and are thus feasible only in onshore applications (AQIS 1993a; Gauthier & Steel 1996; Cohen 1998; Reeves 1999). Granular filtration could in theory be employed shipboard in pressurized containers

[12] Sometimes called media filtration or deep media filtration.

(AQIS 1993a), but space requirements make it impractical (Gauthier & Steel 1996; NRC 1996; Cohen 1998; Reeves 1999; Cohen & Foster 2000).

4. Onshore treatment plants can be run by trained wastewater treatment personnel. It is expected that shipboard treatment plants will be operated and maintained by ships' regular crew members, as an addition to their existing duties (NRC 1996; California SLC 2010). Several researchers have noted that the quality of operation and maintenance will probably suffer (Pollutech 1992; AQIS 1993a; Aquatic Sciences 1996; Reeves 1998), or that operation of treatment systems by better trained personnel in onshore plants would result in superior performance (Cohen 1998; California SWRCB 2002; Brown & Caldwell 2007; California SLC 2010). Maintenance and repair work are also more likely to be done effectively, and needed replacement parts obtained more quickly, in onshore plants (AQIS 1993a; Aquatic Sciences 1996; Cohen 1998; Cohen & Foster 2000).

AQIS (1993a) wrote that in shipboard systems "treatment equipment would be subject to operation, repair and maintenance by the crew. With the standards of ship maintenance in some cases having slipped badly for the both hull and machinery, it may be assumed in these cases that ballast water treatment systems would not be accorded a high priority for maintenance and could be easily by-passed or operated at sub-optimal efficiency." Aquatic Sciences (1996) noted with regard to shipboard treatment that "crew standards with respect to operating and maintenance capability in the deep sea fleet are unpredictable at best....there are no guarantees of their effectiveness...Filtration, strainers, or other high maintenance systems are particularly vulnerable" and "are least likely to stay in service particularly in shipboard applications." California SWRCB (2002) concluded that "a landbased treatment facility operated by professional wastewater treatment specialists would allow a better control of the treatment processes." Brown and Caldwell (2007, 2008) concluded that one advantage of onshore treatment "operated and maintained by experienced treatment operators" is "better control in ensuring that the desired level of ballast water treatment occurs."

5. Onshore treatment is more reliable. Operation and maintenance by trained wastewater treatment staff, as well as easier, safer, more consistent and more predictable working conditions (better access and working space; less corrosive conditions; stability; fewer, more predictable time constraints; freedom from hazardous or emergency conditions that may pertain at sea), as discussed above and below, should produce more reliable and consistent performance. Reliability can be further improved by building redundancy into an onshore plant, but this will often be impractical in a shipboard plant due to space constraints. Relative costs will also make this far more difficult in shipboard systems, due to the large difference in the core treatment capacity need in shipboard vs. onshore applications (estimated above at about 3,500 times as much capacity needed in shipboard than in onshore applications to treat all the ballast water discharged into U.S. waters). Thus adding some extra capacity (30% for example) to each treatment plant to provide redundancy in case part of the system breaks down or is taken offline for maintenance would entail a much greater industry-wide cost for shipboard than for onshore treatment approaches, even without considering the added costs due to shipboard space constraints.

Some studies also make the point that bypassng a shipboard treatment plant designed to operate inline during ballasting, or failing to employ it effectively, at any point in the history of the treatment plant could compromise the quality of later discharges, since organisms, including cysts or other resting stages, retained in large numbers sediments at the bottom of ballast tanks could contaminate properly-treated ballast that is loaded later (AQIS 1993a; Reeves 1998). In a section titled "The Virgin Tank," Reeves (1998) explains (regarding ships that enter the Great Lakes) "the concept is that water will always be treated in-stream at the time of intake and the tank will be maintained in a consistently pristine condition...The problem with this appealing concept is that one filter breakthrough or failure to religiously maintain and use the system...throughout the voyages around the world to ports such as Bombay and Naples by a foreign crew will contaminate the tank and vitiate the protection to be achieved when the vessel later shows up in a U.S. or Canadian port."

6. Onshore treatment is more effective. Many of the above advantages—the absence of the space, time and power constraints that characterize shipboard applications, the ability to use common and effective treatment processes that are impractical or impossible at sea, operation and maintenance by trained personnel, and the greater potential to build-in extra capacity and redundancy—will tend to make onshore treatment more consistently effective at removing or killing the organisms contained in ballast water. Other factors—cost factors that make it possible to concatenate a larger and more effective set of treatment processes in onshore plants as discussed in later sections, and the greater adaptibility of onshore treatment discussed below—also raise the potential effectiveness of onshore relative to shipboard treatment. Dames & Moore (1999) reported that onshore treatment provided "complete control of effectiveness," and Lee et al. (2010) stated that compliance with a zero discharge standard is feasible only with on-land treatment.

7. Onshore treatment is safer. Shipboard treatment involves restricted working spaces and difficult and potentially hazardous working conditions at sea (AQIS 1993a; Cohen 1998; Cohen & Foster 2000), which increases the risk of accidents related to treatment processes or materials. For processes that involve the storage and use of biocides or other hazardous chemicals, there is greater risk of harm to personnel in shipboard than in onshore applications (AQIS 1993a; Carlton et al. 1995; Reeves 1998; Cohen 1998; Cohen & Foster 2000) and greater risk of accidental discharge to the environment (Pollutech 1992; AQIS 1993a; Carlton et al. 1995). In addition, because many of the cheapest and most effective physical separation processes cannot be used onboard ships (as discussed above), to achieve a given level of treatment shipboard treatment systems will likely rely on biocides to a greater extent than will onshore systems.

AQIS (1993a) concluded that "the control of occupational health and safety issues would...provide the most difficulty in shipboard systems, particularly if hazardous chemicals are involved," and also noted concerns regarding "hazardous environments created by the treatment equipment, e.g. heat, UV, mechanical movements," etc. on board ships. Lloyd's Register (1995, cited in Reeves 1998) stated that "both inorganic and organic biocides would present a range of health and safety problems related to storage of chemicals, compatibility with cargo carried on board as well as direct and indirect handling of chemicals by crew members." The National Research Council (1996) noted that while "safety issues associated with handling chemicals on board a ship may be of concern," the volume of such chemicals may be small and it should be possible to train ships' crews to handle them safely. Cohen (1998) noted "concerns about crew safety or wear or stress on the ship (i. e. concerns over storage and use of toxic chemicals, corrosion or thermal stresses that arise with various on-board treatments)." Regarding the risk of environmental damage, Pollutech (1992) observed that "the risk of a spill [in onshore plants] would be less than that for all vessels carrying the same chemicals."

8. Onshore treatment is more adaptable. There are greater space restrictions on ships than onshore, and, as discussed in a later section, structural cost factors make treatment components a much smaller part of the total cost of treatment in onshore than in shipboard applications. As a result, if at some point after the initial installation or construction of a treatment plant it is determined that additional treatment components are needed, it is both physically and financially easier to retrofit them in onshore than in shipboard applications. Similarly, it is financially easier to upgrade or replace existing treatment components in onshore than in shipboard applications, even if these changes involve no additional space requirements. Brown and Caldwell (2008) noted that onshore systems would "provide treatment flexibility, allowing additional treatment processes to be added or modified as regulations and treatment targets change"

9. Compliance monitoring and regulation would be easier, cheaper and more effective onshore. The amount of effort and the 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[13] shipboard treatment plants (roughly 300 times as many to treat all discharges into U.S. waters, according to the estimates above), 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 2007). Several studies noted the difficulty of monitoring shipboard treatment and the greater ease of monitoring and inspecting onshore treatment (AQIS 1993a; Cohen 1998; Dames & Moore 1999; Cohen & Foster 2000; California SWRCB 2002; California SLC 2010).

AQIS (1993b) found that one advantage of onshore treatment is that it is "the only arrangement where:

- responsibility for monitoring, control and effectiveness is totally in the hand of authorities at the destination port;

[13] Roughly 20% of the 40,000 cargo ships estimated to be subject to the EPA's Vessel General Permit are foreign-flagged (Albert & Everett 2010). What fraction are foreign-owned is not known.

- beneficiaries of treatment (coastal water users, fisheries and aquaculture industries etc.) have physical evidence of controls in place;
- there is no reliance on actions from originating port authorities or ship operators to ensure that treatment is effective."

Both Dames & Moore (1999) and California SWRCB (2002) noted the value of having the receiving port authorities be responsible for the operation and maintenance of treatment systems. Dames & Moore (1999) noted that onshore treatment removed "the need for reliance on ships' logs (which can potentially be falsified)." Aquatic Sciences (1996) recommended that new initiatives in ballast water treatment "focus on compliance, enforcement and monitoring issues as a major driving force in the selection criteria."

VI.C. Operational Issues Potentially Restricting the Use of Onshore Treatment
[this section was added on 10/27/2010]

Five issues that potentially restrict the use of onshore treatment have been identified in the literature:

1. Several studies noted that some vessels that need to discharge large volumes of water, such as bulk carriers, often being to discharge ballast water before arriving at berth so they can complete discharge by the time the cargo is loaded, and they would not be able to do this if they had to discharge all their ballast water to an onshore treatment facility while at berth (AQIS 1993a; Oemke 1999; Cohen & Foster 2000; CAPA 2000; Rigby & Taylor 2001a). AQIS (1993a) noted that for a bulk carrier "normal vessel operation may involve dumping up to 20% of ballast water in coastal waters as it approaches port." However, AQIS (1993b) also noted that if the "rate at which the cargo is to be loaded is such that the ships ballast pumps can discharge ballast at a comparable or higher rate, deballasting may be carried out entirely while alongside the berth." One solution, then, is when modifying a ship to enable it to discharge to a ballast water receiving system at berth, to design the pipes and pumps large enough to enable the ship to unload its ballast water as fast or faster than it loads cargo. The question then is how expensive is it to do this, and is it so expensive that the overall cost of treating ballast water onshore becomes untenable? Glosten (2002) and Brown and Caldwell (2007, 2008) developed cost estimates explicitly for retrofits on bulk carriers and other vessels that would allow them too deballast at berth during the time they load cargo, and these estimates are used in the next section on costs.

2. Several studies also noted that there are times when a ship discharges ballast water before arriving at berth to reduce draft in order to cross over a shallow bar or to enter a shallow channel (Cohen 1998; Dames & Moore 1998, 1999; Oemke 1999; CAPA 2000, Rigby & Taylor 2001a; California SWRCB; California SLC 2010). None of these, however, provide any data indicating whether this is a rare or a more common circumstance. Several studies note the possibility of addressing this (at least in some circumstances) by offloading some ballast water to a barge before arriving at berth, a practice that some ships at some ports routinely do for liquid cargo (a process called lightering) (AQIS 1993a; Carlton et al. 1995; Dames & Moore 1999; CAPA 2000; Rigby & Taylor 2001a; Glosten 2002; California SWRCB 2002). This would have some cost, of

course. Dames & Moore (1998) suggested that a treatment ship (that is, not just a barge that could take the water and transport it to shore, but a vessel with a treatment plant installed, that is designed to receive ballast *and treat* ballast water from cargo ships) could "service deep-drafted high-risk arrivals that need to deballast during approach to shallow berths at neap tide periods," though whether this would be generally feasible or cost-effective is unclear. An approach applicable to all situations, and probably the least cost option in most, is for the shipping industry to adjust operationally, that is, to send cargo to a port on ships that can reach berth without having to partially deballast first. The industry already does this all the time—that is, shipping companies take into consideration the characteristics of the port and the channels that must be traversed when deciding which ship to send to which port carrying which cargo, and they have a great deal of expertise in selecting the most efficient, least cost option to do so. Adding the additional constraint of not being able to discharge ballast water before arriving at port would have some cost, but the industry is well set up to make the right operational decisions to minimize this. The cost depends on how commonly this circumstance occurs and on how much it would take to work around it, and there doesn't appear to be any data on either of these. It could be a significant cost, or an insignificant one, considering the industry overall.

3. Several studies have noted the possibility of costly delays (Dames & Moore 1998, 1999; Cohen 1998; Oemke 1999; Cohen & Foster 2000; CAPA 2000). In all cases, these appear to be a restatement of issues 1 and 2. That is, (1) if a ship is not allowed to start deballasting before arriving at berth *and* its ballast discharge system isn't modified so it can discharge at berth in the time it takes to load cargo, then it could be delayed; and (2) if a ship is sent to a port where it must cross shallows that require it to reduce its draft and it is not allowed to discharge ballast water into the water, then it must either offload part of its ballast to another vessel, which will involve some delay, or in some cases it might be possible to wait until the tide rises, which will also involve some delay. Since delaying a ship is generally quite costly, the least cost option will in most cases be to outfit the ship with ballast pipes and pumps that are large enough to allow deballasting to occur as rapidly as cargo loading, and to ship cargo to ports on ships that can enter those ports without having to offload ballast or wait for higher tides.

4. Some studies mentioned that cost recovery may be an issue (Dames & Moore 1998; Oemke 1999; Cohen & Foster 2000). While there is a cost recovery question associated with onshore treatment—that is regional governments and ports will have to decide whether they want to pay for part or all of the cost of ballast water treatment, or whether ships will be charged a fee for having their ballast treated in an onshore plant, with the fees set at a level that pays for the construction and operation of the plant—there doesn't appear to be any cost recovery issue that is a barrier to implementation of onshore treatment.[14] In reality, regional governments and ports

[14] Of the studies that mention cost recovery, the only actual discussion of the issue (beyond a few word mention of it) appears to be in Cohen & Foster (2000), as follows: "One question that arises with on-shore treatment is who would pay for the construction and operation of treatment facilities, the ships or the ports? If ships were required to treat their ballast water discharges and onshore treatment was the cheapest approach, either shipping companies, ports or, conceivably, independent entrepreneurs might choose to construct treatment facilities. If ports or independent parties were to do so, they could recover

face the same decision with shipboard treatment, though it's not as obvious. Thus, a regional government (such as a state or a country) could adopt ballast water discharge requirements and then reimburse ships for the costs incurred in meeting those requirements, if it decided it was in the public interest to do so. Alternately, ports could offer to reimburse ships that voyage to the port for any ballast treatment costs incurred on that voyage, in order to entice shipping companies to use the port. Or regional governments and ports could decide to let the ships pay for the cost of treating their ballast water.

5. Several studies mention one or another element of the cost of onshore treatment, or just mention costs generally, as a disadvantage of onshore treatment (Cohen 1998; Dames & Moore 1998: "expensive connection problems"; Dames & Moore 1999: "high costs of construction"; Rigby & Taylor 2001b: "high cost of the installation"; California SLC 2010: costs "may be prohibitive...the acquisition of land for facility construction...would be...costly"). There clearly are substantial costs associated with treating ballast water onshore, just as there are with treating ballast water onboard ships. Whether it is an advantage or a disadvantage of onshore treatment compared to shipboard treatment depends on whether the total costs of onshore treatment are higher or lower than the total costs of shipboard treatment that achieves the same task, that is managing the ballast water discharged to a region to the same regulatory standard. This is discussed in the following section on costs.

Dames & Moore (1999) states that onshore treatment is "an expensive option for ports with a low incidence of high-risk arrivals." Dames & Moore were assuming that only ballast discharges identified as high risk would be required to undergo treatment, rather than all ballast discharges, but the general point is valid: constructing and operating a treatment plant in ports that receive little ballast water will result in high costs per MT of ballast water treated at that site. Both the AQIS (1993a) study of onshore treatment in Australia and the CAPA (2000) study of onshore treatment in California made the same point, and proposed alternatives. AQIS (1993a) proposed deploying barges to receive ballast discharges in smaller ports that received little ballast water, which would periodically transport the collected ballast water to treatment plants located in the larger ports. CAPA (2000) decided that building a treatment plant in Port Hueneme, which according to the data available to them received only 687 MT/y (an average of <500 gallons/day), would not make any sense. Instead they proposed that an on-land pipe system and storage tanks be built there to receive and store ballast water, which would periodically (every 6-7 months in their plan) be barged to treatment plants in the ports of Los Angeles or Long Beach, a short distance to the south. The statement that onshore treatment requires building a separate treatment plant everywhere that a ship comes into port, as it is sometimes framed, is not correct.

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costs and turn a profit by charging ships appropriate fees for receiving and treating their ballast water. A potential advantage to the shipping industry of on-shore treatment is that plant construction costs are more likely to be subsidized by federal or state governments—just as the cost of constructing wastewater treatment plants was subsidized during the implementation of the Clean Water Act—than would the cost of constructing or installing treatment plants on board ships. For example, low-interest or no interest loans are available for the construction of on-shore facilities to treat ballast water in California, through the State Revolving Fund administered by the State Water Resources Control Board, which is a form of subsidy."

At small ports the question of whether to build an onshore treatment plant, or to build an onshore storage tank with periodic transport of stored ballast to larger ports, or to deploy a barge to collect and transport ballast water from ships, will be decided based on the relative costs of each.

VI.D. Cost of Onshore vs. Shipboard Treatment

[this section was added 10/27/2010]

As the review of past studies on onshore treatment showed, there is broad and possibly unanimous agreement that onshore treatment of ship's ballast water is technically feasible: we have the technological ability to transfer ballast water off of cargo ships and into an on-land receiving system, a treatment ship, or a transport barge; we can move ballast water through pipes and into storage tanks on land; and we have a broad array of proven technologies that we can use to treat ballast water on a treatment ship, and an even broader array that we can apply on land; and to a fair degree on a treatment ship and to a greater degree on land, we can concatenate as many of these treatment technologies as we need to achieve the desired (potentially very rigorous) level of treatment. The question of feasibility, then, really comes down to cost. Can this be done at a total cost that is not obviously impractical? It is beyond the scope of this committee's work to try to figure out what the maximum acceptable total cost of treating the nation's ballast discharges might be. Fortunately, we don't need to do that. A far simpler question is how does the total cost of treating ballast water onshore compare to the total cost of treating ballast water on ships? If shipboard treatment is considered economically feasible[15], and onshore treatment is not substantially more costly, then onshore treatment must be economically feasible also.

In the following discussion we compare the total costs, as completely as we are able to estimate them, of the onshore or shipboard treatment needed to deal with all the ballast water discharged into California waters, and then extend that to all U.S. waters. The California estimate is based on the most relevant and complete estimate of onshore treatment costs available, the CAPA (2000) study. This is augmented by other available sources of information to estimate the onshore treatment costs that were not included in the CAPA estimate. Shipboard treatment costs for California are based on the number of distinct ships arriving in California ports and the total ballast pump capacities of those ships derived from information compiled by the California State Lands Commission from the Ballast Water Reporting Forms submitted by ships arriving in California since January 1, 2000 (California SLC 2010), and on recently published estimates of

[15] We don't know whether there has yet been any official determination by the U.S. EPA or other government bodies that shipboard treatment of ballast water is in fact economically feasible, and we are not making that determination here. We only note that some number of shipboard ballast water treatment systems have been installed on ships and are in operation (Lloyd's Register 2010); that the interest and activities of the shipping industry and the equipment manufacturers and the investors in shipboard ballast water treatment systems suggest that they believe that it is economically feasible; and that the ballast water convention written by the IMO, the ratification of that convention by various port states, the regulations proposed by the U.S. Coast Guard, and the convening of this committee and the charge questions provided to it by the Office of Water suggest that those entities also believe that shipboard treatment is economically feasible. If it is not, then most of this report will be of little value.

shipboard treatment system costs in Lloyd's Register (2010) and Glosten (2010).

For the U.S., onshore costs are estimated by multiplying the California onshore cost by the ratio between the total amount of ballast water, from both foreign and domestic sources, discharged into U.S. waters and the amount of such discharge into California waters. These figures are derived from the information compiled and published by the National Ballast Information Clearinghouse based on the Ballast Water Reporting Forms submitted by ships arriving in U.S. ports in 2004-2005, which is the most recent data available (NBIC 2007). Shipboard treatment costs are based on the number of distinct ships estimated to be subject to the VGP (Albert & Everett 2010) and the recent estimates of shipboard treatment costs (Lloyd's Register 2010); Glosten 2010). As there does not appear to be any data available on the total ballast pump capacities of the ships subject to the VGP (Albert Ryan, pers. com. to the committee, public conference call 10/26/2010), we used the ballast pump capacity figures for ships arriving in California (California SLC 2010).

[to be completed]

VI.E. Potential Effectiveness of Onshore Treatment

[this section has not yet been drafted]

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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.

[this material was updated from the 10/20/2010 document, primarily to add more detal regarding estimates of the number of treatment plants and treatment capacity needed in onshore and shipboard approaches].

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 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 ships arriving or discharging ballast in these locations (for the number of treatment plants), multiplied by the average ballast pump capacity of these ships (for the treatment capacity). For sites with onshore studies that include on-land treatment plants, the project period for the estimate is 30 years based on the estimated useful life of an on-land treatment plant (Appendix 1). 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 in thsi Appendix *conservative* adjustments are those that tend to raise the number of treatment plants or the total treatment capacity needed for onshore treatment, or to lower those numbers for shipboard treatment.

<u>Port of Milwaukee (overseas ships only)</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 would call at the Port consisting of a combination of (a) new ships that come into service to replace ships that had called at the Port during the first year, and (b) other ships, including other new ships and old ships that hadn't called at the Port during the first year. With a typical useful working life for a cargo ship of 25 years, approximately 19/25 of the ships calling at the Port in the first year will go out of service and be replaced by other vessels during the remainder of the 20-year period. Since raising the number of ships raises the number of treatment plants and the total treatment capacity that would need to be installed to accomodate shipboard treatment, we conservatively adjust the number of ships by counting only the additional ships that call as replacements for the ships that called during the first year, and ignoring other ships. The estimated number of distinct ships, and of treatment plants needed, is thus 19 (= 11 x (1 + 19/25)).

Shipboard estimate, treatment capacity: In describing ships at the Port of Milwaukee, Brown and Caldwell (2008) state that "typically, cargo ships have two to three pumps that pump the ballast water to one of the various discharge locations on the ship...In general, each of the pumps within the ballast water tanks has a capacity that ranges from 1,000 gpm to 5,000 gpm, and often two of the pumps operate simultaneously." Thus, these ships typically have ballast pump capacities of 2,000 gpm (≈450 MT/h) to 10,000-15,000 gpm (≈2,300-3,400 MT/h). For the estimate, we assumed an average capacity of 1,200 MT/h. 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 was increased to 5. This is a conservative adjustment, since the calculated need over 30 years is for only 4.5 treatment ships. The total treatment capacity of the 18 on-land plants and 5 treatment 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 ballast pump capacities are about 10% of typical ballast loads (AQIS 1993a, Table 4.1), thus the average ballast pump capacity for Australian vessels is estimated to be 550 MT/h. This is almost certainly a substantially conservative estimate, since AQIS (1993a, Table 4.1) lists typical ballast pump capacities for ships in Australia ranging from 500 MT/h (for small containerships) to 6,000 MT/h (for large bulk carriers), with an unweighted average for different ship types of 2,089 MT/h. Using a higher estimate of average ballast pump capacity would produce a correspondingly higher estimate of the total treatment capacity needed.

Adjusting the ship numbers to a 30-year period by adding only the expected number of replacement ships (and ignoring other ships, a conservative adjustment) yields 2,160 distinct ships requiring 2,160 treatment plants. With an average ballast pump capacity of 550 MT/h, a total treatment capacity of 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 used in the CAPA (2000) report.

The estimates in CAPA (2000) were based on some of the earliest ballast discharge data collected by the U.S. Coast Guard 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 (12,251,089 MT/y, see table below) and the CAPA (2000) estimate for California discharge (3,302,988 MT/y, summed from Table 5.2 in CAPA (2000)), yielding an estimate of 1,814 MT/h of onshore treatment capacity needed in California (or nearly 4 times the estimate in CAPA (2000)).

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	Domestic			Foreign			Total
	Reported Discharge	Reporting Rate	Estimated Discharge	Reported Discharge	Reporting Rate	Estimated Discharge	Estimated Discharge
Source:	Table 8	Table 4		Table 6	Table 3		
DATA FOR 2004-2005							
SFCMS	4,379,050	104.8	4,178,483	2,975,652	73.7	4,037,520	8,216,003
LOSMS	4,612,242	78.6	5,867,992	5,741,283	98.4	5,834,637	11,702,629
SDCMS	3,452,378	77.7	4,443,215	112,825	80.4	140,330	4,583,545
California			14,489,690			10,012,487	24,502,177
ANNUAL DATA							
California			7,244,845			5,006,244	12,251,089

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

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

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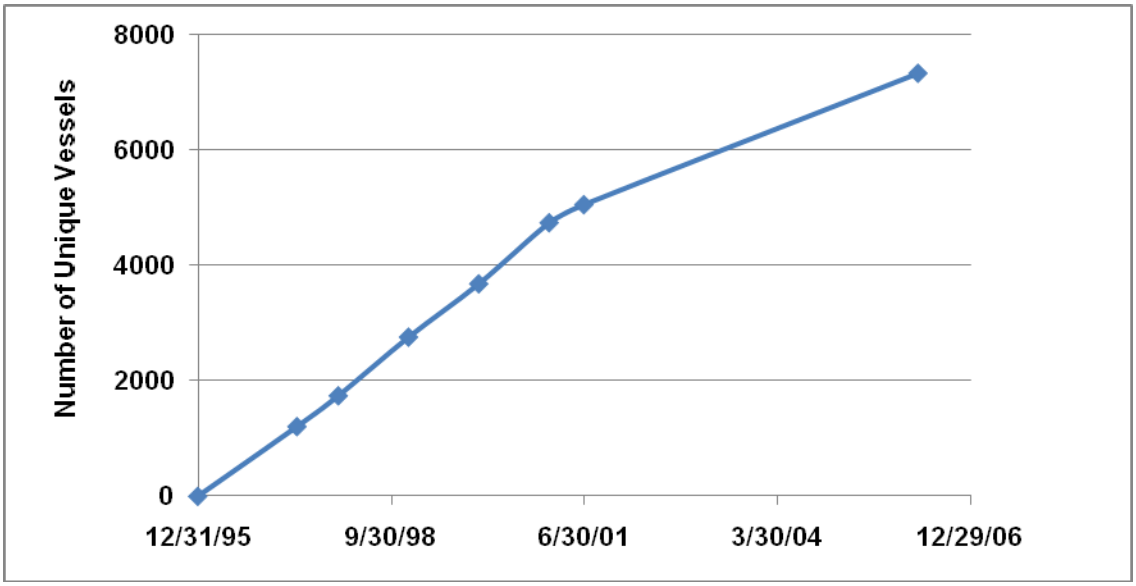
Figure 1. Cumulative number of unique ships arriving at California ports since January 1, 2000. Includes a small number of unmanned barges (a total of 28 through June 2005).



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

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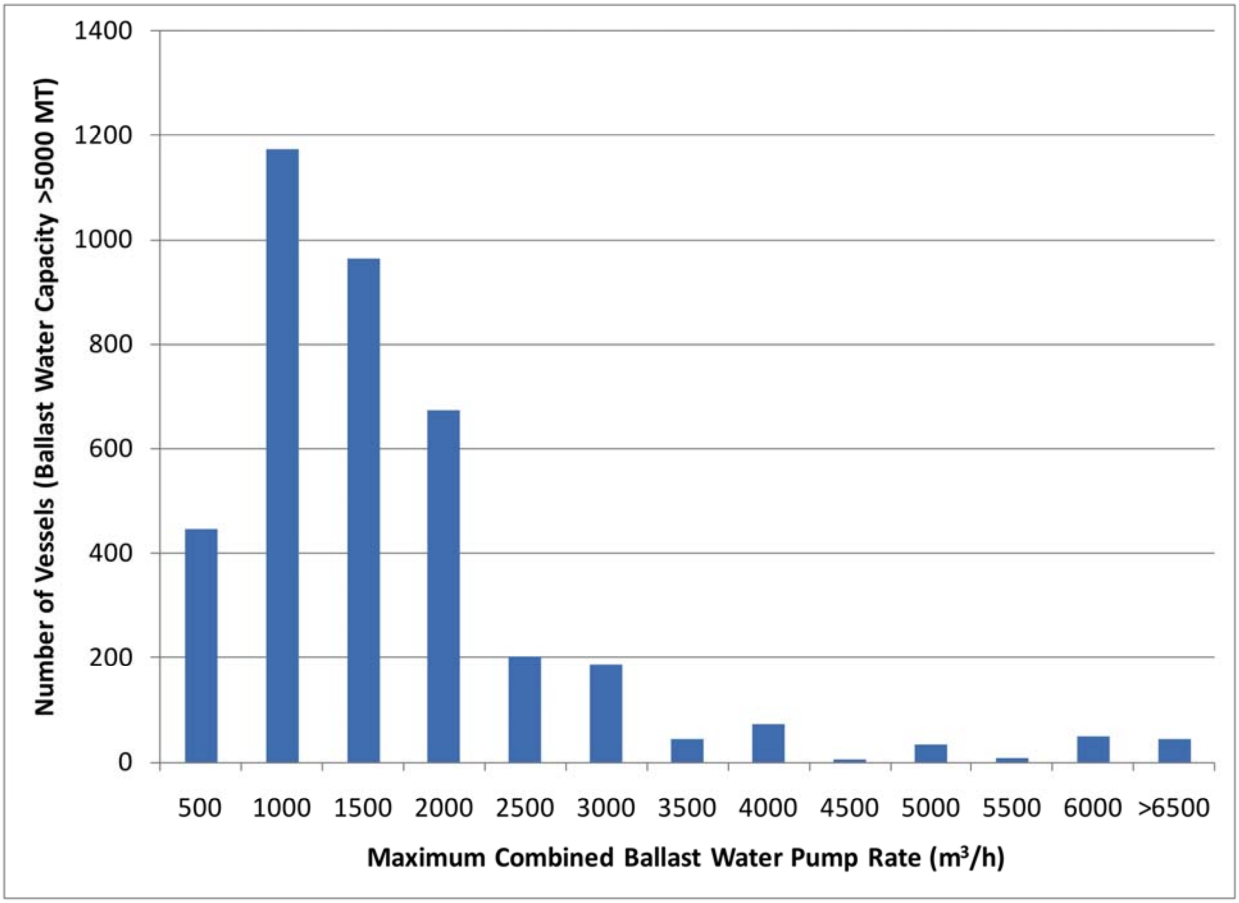
Figure 2. Total ballast pump capacities of ships that call at California ports. Source: California SLC 2010, Fig. VI-3.



As mentioned, not all vessels discharge ballast water on arriving at a California port, so not all of the distinct arriving ships may need to install treatment plants. Thus these numbers might overestimate, perhaps substantially, the number of plants and the treatment capacity needed for shipboard treatment. How significant could this overestimation be? On average, only 20% of ship arrivals at California ports report discharging ballast water (California SLC 2010); however, there is no independent verification of whether ships have or have not discharged ballast water, and there are reasons to suspect that ships often fail to report some of their discharges. Glosten (2002) reported that they "were often told by agents and operators that their vessels never discharge ballast in Puget Sound. However, we found that almost every vessel surveyed discharged ballast at some point while they were in port, usually for trim and list control, while loading and off-loading cargo." Glosten (2002) concluded that the under-reporting occurred because many ship operators mistakenly excluded such common practices from their definition of ballast discharge. However, there is also a financial incentive for ship operators to not report ballast discharges: a ship reporting that it intends to discharge ballast is more likely to have its ballast tanks sampled, which is an inconvenience that involves some risk of delay, and which at least theoretically increases the chance that it will be found to be out of compliance and subjected to penalties. Studies in Australia (Lockwood 1999), the Great Lakes (Reeves 1998) and Washington (Harkless 2003; Lyles 2004) found evidence that ships routinely misreported their ballast management activities (see also Cohen & Foster 2000 at footnote 163). Harkless (2003) reported that many Chief Mates admitted that they intentionally reported false ballast water information in order to satisfy regulators.

Even if the figure of ballast discharge by only 20% of California ship arrivals is accurate, much more than 20% of the individual ships would probably need to install treatment plants to treat the ballast discharged on *some* voyages. For example, if each ship discharged ballast on half of its arrivals at California ports, then 100% of ships would need to treat ballast water even though only 50% of arrivals involved ballast discharges. As a sensitivity test, if we assume the most extreme hypothetical case of only 20% of ships needing to treat ballast water, then the estimates for California would be as follows (compare to Table VI.B-3):

	Number of Treatment Plants		Total Capacity of Treatment Plants (MT/h)	
Site	**Onshore**	**Shipboard**	**Onshore**	**Shipboard**
California	16	2,623	1,814	3,766,628

In this case the number of treatment plants needed for shipboard treatment is 164 times the number needed for onshore treatment (down from 820 in Table VI.B-3) and the treatment capacity needed is 2,076 times the need with onshore treatment (down from 10,382 in Table VI.B-3). Though less, the difference is still striking.

<u>United States</u>

Onshore estimate: To estimate the number of onshore treatment plants and the treatment capacity needed in the United States, we started with the estimates for California derived above. These we multiplied by the ratio between the estimated total ballast water discharge in the United States (239,989,668 MT/y derived from Miller et al. 2007 by the methods described earlier, see table below) and the estimated discharge in California (12,251,089 MT/y). This yielded an estimate of 314 onshore treatment plants needed with a total treatment capacity of 35,549 MT/h.

	Domestic			Foreign			Total
	Reported Discharge	**Reporting Rate**	**Estimated Discharge**	**Reported Discharge**	**Reporting Rate**	**Estimated Discharge**	**Estimated Discharge**
US 2004-05	183,792,889	48.9	375,854,579	73,720,328	70.8	104,124,757	479,979,336
US annual			187,927,290			52,062,379	239,989,668
CA annual			7,244,845			5,006,244	12,251,089

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 ballast pump capacities comparable to the California data in Figure 2 are available for the U.S. as whole. We used California's average ballast pump capacity of 1,436 MT/h, to yield an estimate of total treatment capacity of 124 million MT/h need for shipboard treatment.

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(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>

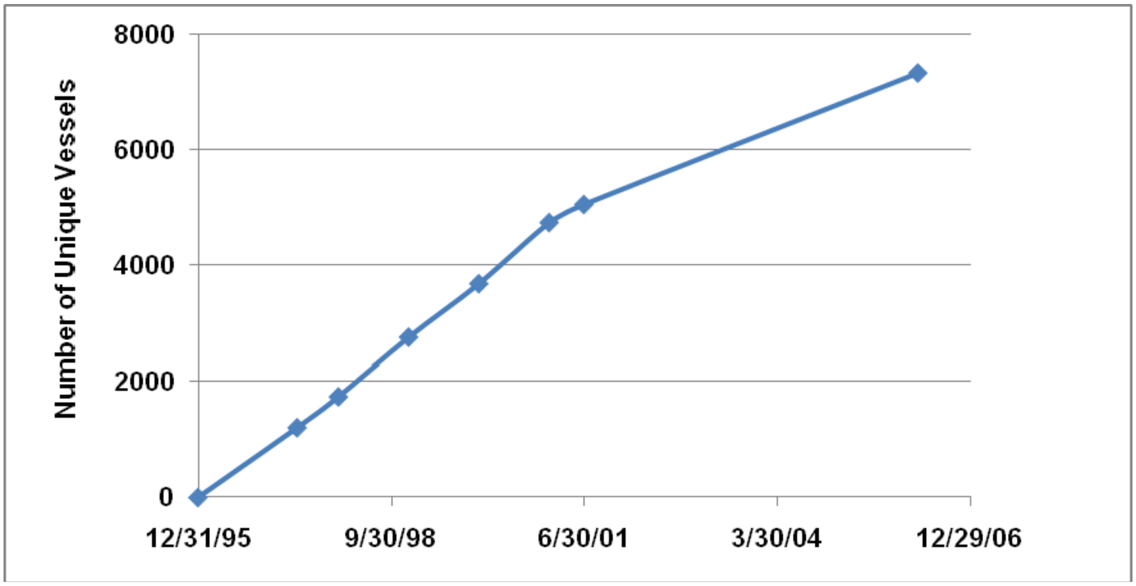
Onshore estimate: CAPA (2000) estimated that 10 on-land treatment plants (one at each of ten ports) with a total treatment capacity of 489 MT/h could treat the ballast water discharged into California waters. However, the port descriptions in this study suggested that it would be more economically efficient 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.

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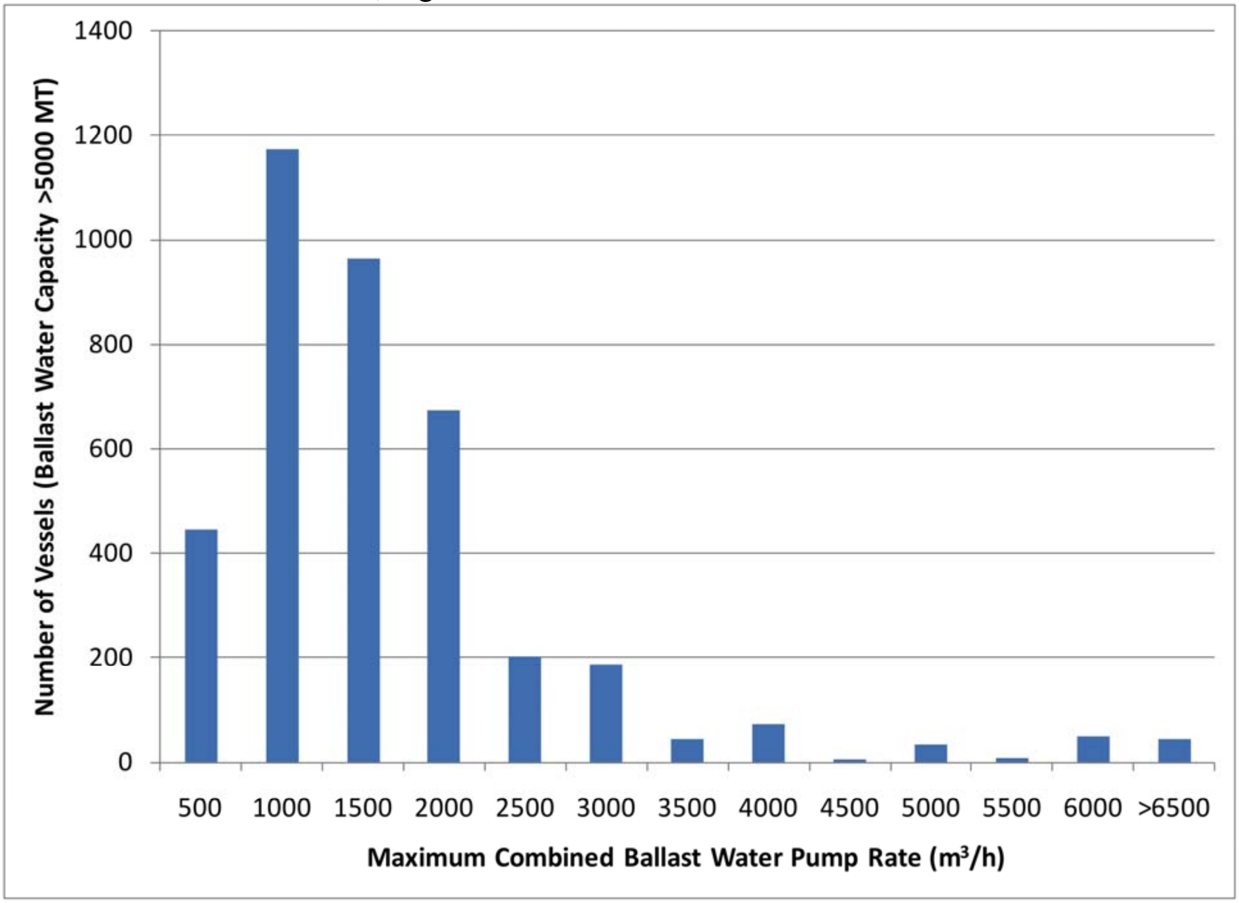
Figure 2. Maximum ballast water pumping rates of ships that call at California ports.
Source: California SLC 2010, Fig. VI-3.



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.