



Commercial Marine Emission Inventory Development

Final Report

EPA420-R-02-019
July 2002

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Final Report

Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

Prepared for EPA by
Environ International Corporation
EPA Contract No. 68-D-00-265
Work Assignment No. 1-11

**COMMERCIAL MARINE
EMISSION INVENTORY
DEVELOPMENT**

FINAL REPORT

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Revised
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EXECUTIVE SUMMARY

In this report, emissions were estimated for vessels propelled by Category 3 engines (those with cylinder displacements above 30 liters). Chapter 1 reviews the emissions data available for these types of engines and provides estimates of average emission factors to be used in later emission estimates. Chapter 2 details which ports were considered similar and matched to each of several ports for which detailed port call data was available from earlier EPA work (Arcadis, 1999a and 1999b) in order to estimate emissions for all ports. Chapter 3 provides a description of how the emission estimates near and at US ports were performed and summarizes results for all ports combined. Chapter 4 describes and summarizes emissions estimates for these type of vessels operating in US waters outside the area covered by the Chapter 3 estimates. Chapter 5 estimates future year emissions at US ports. Chapter 6 provides a sensitivity analysis for a number of assumptions and estimates used in the compilation of the Chapter 3 results.

In this analysis, the Category 3 engine emissions, shown below in Table ES-1, were considered to be the emissions from propulsion engines of merchant vessels (including passenger vessels but excluding barge carriers, fishing, supply vessels, and tug) and from auxiliary engines for passenger and reefer vessels only, while other vessel's propulsion and auxiliary engines were considered to be Category 2 or 1. Auxiliary loads were calculated for all merchant vessels, but evidence was discovered indicating that Category 3 engines were used only for auxiliary loads for two types of vessels (passenger and reefer) that have high electrical loads. The ports work was not able to distinguish between US and foreign flagged vessels from the data available. The "Between Port" estimates include transit between 25 nautical miles and 200 statute miles from US shores but may exclude some vessel traffic transit within 25 nautical miles of shore but not within 25 nautical miles of the next or last port of call.

Table ES-1. Emission estimates for Category 3 engines. (1,000 tons/year).

Emission Estimate	HC	CO	NOx	PM	SO₂
Chapter 3 Category 3* 1996 Near Ports	5.2	11.5	101.0	9.2	68.2
Chapter 4 Category 3* 1996 Between Ports	2.1	4.2	88.8	7.8	58.9
1996 Total Emissions	7.3	15.7	189.8	17.0	127.1

* Category 3 were summed as transit mode emissions of merchant vessels plus hotelling emissions for passenger and reefer vessels including steamships.

1. REVIEW OF EMISSION FACTORS

INTRODUCTION

The purpose of this chapter is to provide an estimate of the emission factors for Category 3 engines for use in estimating emissions at US ports. EPA has defined 3 categories of marine engines as described in Table 1-1 (EPA, 1999b). Many previous reviews and emission studies [EPA (2000), Environment Canada (1997), Lloyds (1995), ETC (1997), BAH (1991), Environment Canada (1999), and TRC (1989)] have determined and reviewed emission estimates, but did not distinguished between these EPA-defined Categories. Based on these reviews and studies, this review seeks to determine appropriate emission factors for Category 3 engines specifically. Based on the Arcadis (1999a and 1999b) reports, activity information was available in units of engine power (kW) and hours of use, so emission factors in emissions per work units (g/kW-hr) were needed.

Table 1-1. EPA definition of engine categories.

Category	Displacement (liters/cylinder)
Category 1	<5.0
Category 2	$5.0 \leq \text{disp.} < 30$
Category 3	≥ 30

Historic EPA emission rate estimates include the official guidance for emission inventory preparation (EPA, 1992), which are found in BAH (1991), but support documents for recent rulemakings (1999a and 1999b) used different emission factors. Historic estimates were reviewed here for comparison with recommended emission factors for Category 3 engines.

Much of the data from which these official guidance EPA emission factors were derived was not referenced, and a number of studies [ETC (1997), Lloyds (1995), Environment Canada (1997), Lloyds (1997) or Environment Canada (1999)] determining emissions rates have been completed since the time of that guidance. Some of the more recent data has been incorporated into SIP emission inventories for the Houston-Galveston and California ports, which are currently used for ozone modeling and planning for attainment demonstration (Acurex, 1996; Starcrest, 2000). A review of the emissions data for Category 3 marine engines is presented here with a recommendation of the average values to use in emission inventory estimates.

EPA EMISSION FACTORS GUIDANCE

Official EPA guidance for emission factors for large commercial vessels is shown in Table 1-2. (BAH, 1991 and EPA 1992) The guidance for emission factors did not distinguish between slow speed (direct-drive) and medium speed (geared or electric drive) engines and was limited in its consideration of engine displacement. This emission factor guidance did include estimates for steamships that represent a small number of aging steamships still operating in US waters powered by steam generated from boilers.

Table 1-2. EPA emission factors for large ships propulsion power(BAH, 1991).

Propulsion Type	NO_x (kg/tonne)	HC (kg/tonne)	CO (kg/tonne)	PM (kg/tonne)
Motorships	69.6	3.0	7.7	4.2
Steamships (full power)	8.1	0.2	0.9	7.2
Steamship (maneuvering)	7.1	0.1	0.4	2.5

All emission estimates were converted from lb/1000 gallons units using 7.9 lb/gallon fuel density for heavy fuel oil.

For smaller vessels, such as push boats, tugs, ferries, and other similar sized work boats, EPA provided emission estimates ranked by size of engine as shown in Table 1-3. The data shown in Table 1-3 exhibited many inconsistencies from one power level to another that were not explained.

Table 1-3. EPA (1992) emission factors for small ship propulsion power.

Engine Size	Mode	NO_x (kg/tonne)	HC (kg/tonne)	CO (kg/tonne)	PM (kg/tonne)
< 500 hp	Full	38.7	3.0	8.2	2.4
	Cruise	54.8	7.2	6.7	2.4
	Slow	47.5	8.0	8.3	2.4
500-1000 hp	Full	42.3	3.4	8.6	2.4
	Cruise	42.3	2.4	11.4	2.4
	Slow	23.5	2.4	8.8	2.4
1000-1500 hp	Full	42.3	3.4	8.6	2.4
	Cruise	42.3	3.4	8.6	2.4
	Slow	42.3	3.4	8.6	2.4
1500-2000	Full	66.5	2.4	33.5	2.4
	Cruise	87.8	3.4	6.3	2.4
	Slow	52.3	3.4	17.2	2.4
2000+ hp	Full	56.3	3.0	13.5	2.4
	Cruise	55.2	2.4	11.0	2.4
	Slow	59.1	3.2	8.4	2.4

All emission estimates were converted from lb/1000 gallons units using 7.1 lb/gallon fuel density for diesel fuel. Estimates for auxiliary engines were also provided by engine size and are shown in Table 1-4.

This data also displayed many inconsistencies from one power level to another that were not explained. Auxiliary engines are primarily used to provide electric power for the ship while in dock, but may also be used for powering cranes, winches, pumps, bow thrusters, and other uses for the vessel. The larger ocean-going vessels have been reported to typically use 500 to 2,000 kW auxiliary engines for onboard electrical power while only smaller fishing or recreational boats would use engines at 40kW or below for similar purposes.

Table 1-4. EPA (1992) emission factors for auxiliary engine power.

Engine Power	NO_x (kg/tonne)	HC (kg/tonne)	CO (kg/tonne)	PM (kg/tonne)
20 kW	67.2	20.3	7.5	2.4
40 kW	31.8	40.1	9.5	2.4
200 kW	19.7	2.5	8.8	2.4
500+ kW	41.3	11.5	6.8	2.4
Steamship	4.6	0.4	0.5	1.3

Emission estimates converted from lb/1000 gallons using 7.1 lb/gallon fuel density for diesel fuel.

In addition to auxiliary engines generating electricity, large vessels often maintain small heater boilers for a variety of reasons, such as to provide hot water, regardless of the propulsion engine type. EPA has no guidance for incorporating emissions from these boilers, though the steamship emissions rates in Table 1-4 would likely be appropriate because the boilers are likely to be of similar design and use similar fuels.

PUBLISHED REVISED EPA EMISSION FACTORS

EPA has recently revised emission factor estimates in the Regulatory Impact Analysis (RIA) and published a rulemaking for commercial marine vessels. (EPA, 1999a & 1999b) In the absence of a revised official EPA guidance for determining emissions from commercial marine vessels, the emission factors used in the EPA's RIA have been used as the best available information. (Starcrest, 2000)

In the RIA (EPA, 1999b), EPA estimated the emission factors in accordance with the defined engine categories. In Tables 1-5 and Table 1-6 are the EPA-estimated base emission factors for marine engines for each category of engine. These emission factors were applied to both propulsion and auxiliary engines.

Table 1-5. Baseline emission factors for category 1 marine engines (taken from Table 5-3, EPA 1999b).

Power Range [kW]	HC [g/kW-hr]	NOx [g/kW-hr]	CO [g/kW-hr]	PM [g/kW-hr]
37-75	0.27	11	2.0	0.90
75-130	0.27	10	1.7	0.40
130-225	0.27	10	1.5	0.40
225-450	0.27	10	1.5	0.30
450-560	0.27	10	1.5	0.30
560-1000	0.27	10	1.5	0.30
1000+	0.27	13	2.5	0.30

For Category 2 and 3 engines, EPA (1999b) estimated emission rates as shown in Table 1-6. For the Category 2 engines, the average values shown in Table 1-6 were those average values used to estimate the emissions reductions from the new emission standards. (Samulski, 1999) Category 2 engines have been either 2-stroke (GM-EMD or Fairbanks-Morse engines) or 4-stroke engine designs with rated speeds typically above 700 rpm using either geared or diesel-electric propulsion drives. For Category 3 engines, EPA relied on base emission estimates by Corbett and Fischbeck (1998) who in turn used emission factors determined from Lloyds (1995). In order to convert the Lloyds emission factors from kilogram per tonne of fuel consumed to gram per kilowatt-hr, the fuel consumption estimates in Lloyds (1995) of 195 (g/kW-hr) for “slow speed” and 210 (g/kW-hr) for “medium speed” engines were used. The term “slow speed” engine refers to engines that have rated speeds below 300 rpm and are exclusively 2-stroke engines directly driving the propeller. The term “medium speed” refers to Category 3 engines with rated speeds typically of 300 to 700 rpm that are typically 4-stroke engines either geared or diesel-electric driving the propeller.

Table 1-6. EPA (1999b) baseline emission factors for category 2 and 3 engines.

Engine Category	HC [g/kW-hr]	NOx [g/kW-hr]	CO [g/kW-hr]	PM [g/kW-hr]
# 2 (5-30 l/cylinder)	0.134	13.36	2.48	0.32
# 3 Medium Speed (> 300 rpm) (> 30 l/cylinder)	0.5*	12*	1.6*	Fuel sulfur dependence
# 3 Slow Speed (< 300 rpm) (> 30 l/cylinder)	0.5*	17*	1.6*	Fuel sulfur dependence

* Converted from kg/tonne units in Lloyds (1995) using the 195 (g/kW-hr) for “slow speed” and 210 (g/kW-hr) for “medium speed” engines.

Corbett and Fischbeck (1998) used one average emission factor for particulate determined from Lloyds, however Lloyds (1995) found the particulate emissions from marine engines are highly dependent on the fuel sulfur. In order to take advantage of this functional dependence, the Lloyds information was incorporated into an equation as shown in Figure 1-1 and converted to a useful unit (g/kW-hr) using the fuel consumption estimates above.

Also, vessels will use auxiliary boilers to provide steam and hot water. These emission sources are typically very small and insignificant sources of emissions. So only for the sake of completeness, the current emission factors for these boilers are shown in Table 1-7.

Table 1-7. Auxiliary boilers emission factors (EPA, 1992).

Engine/Boiler Type	NO_x (kg/tonne)	HC (kg/tonne)	CO (kg/tonne)	PM (kg/tonne)
Heavy Fuel	4.6	0.4	-	1.3
Distillate Fuel	2.8	0.4	0.5	1.9

REVIEW OF EMISSIONS STUDIES

The review of the available emission studies is presented here with an estimate of the average emission rate to be used in estimating the emissions inventory for Category 3 marine engines. More data are available for NO_x emissions with some data on carbon monoxide (CO). In most cases, total hydrocarbon (THC) data was collected with grab samples, which are known to under represent the actual hydrocarbon emissions because of hydrocarbon losses to the walls of the bag or other collection container used to “grab” a sample, so very little data are available on THC emissions. Discussed in more detail below, data on particulate matter (PM) emissions are sensitive to the sulfur level of the fuel, so the range in emissions levels was found to be dependent on the quality of the fuel used during emission testing and an alternate recommended approach was suggested.

EPA (2000)

EPA (2000) contracted a review of emission factors and fuel consumption for commercial marine vessels. The summary emission estimates relied exclusively on data from ETC (1997) and Lloyds (1995). Other studies available [Environment Canada (1997), Lloyds (1997) or Environment Canada (1999), TRC (1989)] were not considered because emission measurements would need to be converted from the measured units in kg/tonne to g/kW-hr units through a conversion with an estimated average fuel efficiency value. The EPA (2000) study did not attempt to distinguish emissions by the EPA-defined engine categories.

The emission estimates provided by EPA (2000) were not explicitly included because those estimates did not distinguish between engine categories, used a limited data set, and included no “slow speed” engines. EPA (2000) had included data only if the engine were tested over a range

of operating loads to investigate the effect of load on emissions and fuel consumption. As discussed for the Lloyds (1995) data below, no “slow speed” engines were tested on multiple operating modes, so EPA (2000) included no slow speed engines in their analysis. The analysis in this report attempted to include as much data as possible, so the average emission rates were determined at one similar operating load level, the highest load for which data existed. However, as estimated by EPA (2000) for a consistent set of data including Category 1, 2, and 3 medium speed engines, one would expect that specific emissions (in units of g/kW-hr) would increase as the relative load (expressed as a percentage of full power) load decreases for slow speed engines as well as that demonstrated in EPA (2000) for medium speed engines.

Lloyds (1995)

In the EPA (2000) report, the contractors concluded that many of the emission measurements presented by Lloyds (1995) had inconsistent or unrealistic air fuel ratios making the results suspect. EPA provided the individual emission data points from Lloyds (1995) for which the contractors deemed the emission estimates to meet their quality assurance criteria. Data was supplied over a wide range of operating modes for some engines and only over few or single operating modes for the other engines. The engine specifications were not provided by Lloyds (1995) except for engine rated power and speed.

From a scan of engine specifications found in MER (2001), Category 3 engines are rarely found to have ratings less than 2,000 kW or rated speeds greater 750 rpm therefore Lloyds engines with less than 2,000 kW ratings were considered Category 2 engines for purposes of determining emission estimates. Using this definition to determine engine category and type and as shown in Table 1-8, the data from this study used in EPA (2000), which only used the data where vessels were tested over the full range of loads, was from medium speed (>300 rpm) Category 2 and 3 engines.

Table 1-8. Diesel engine specifications from Lloyds (1995) where emission values were considered accurate by EPA (2000) tested at single or multiple modes over the load range.

Vessel	Load Range	Model Year	Speed (rpm)	# of Engines	Rated Power (kW)	Estimated Category*
B5	Full	1986	595	1	3963	3
D1	Full	1975	600	1	3042	3
R2port	Full	1987	510	2	6545	3
R3port	Full	1978	512	2	4780	3
R3stbd	Full	1978	520	2	4780	3
R4	Full	1978	570	1	4246	3
R7gen	Full	1987	1050	2	1400	2
R7port	Full	1987	510	2	7700	3
TK3	Full	1978	450	1	3257	3
TK5	Full	1979	750	1	745	2
TG1push	Full	1965	445	1	1350	2
TG6push	Full	1989	735	1	1270	2
R2cent	Partial	1987	510	2	6900	3
R7cent	Partial	1987	1050	2	1400	2

Vessel	Load Range	Model Year	Speed (rpm)	# of Engines	Rated Power (kW)	Estimated Category*
TK1	Partial	1978	735	1	745	2
TG3frun	Partial	1969	600	1	1260	2
R8port	One Point	1980	155	2	5300	3
R8stbd	One Point	1980	155	2	5300	3
R9port	One Point	1980	153	2	5300	3
R9stbd	One Point	1980	155	2	5300	3
TK6	One Point	1970	131	1	4297	3
TK9	One Point	1977	110	1	13313	3

* This estimate made so that Category 2 engines are those with less than 2,000 kW ratings.

The data in Table 1-8 is a more complete listing of valid available data from Lloyds (1995) than was used in the EPA (2000), which had only used the data where the emissions tests were tested over the full load range.

ETC (1997)

The ETC report determined emissions for a variety of engines found on Coast Guard vessels. From the engine models and specifications found in MER (2001), none of the engines tested could be considered Category 3 with the engines fitting either the Category 2 or Category 1 classification. Emissions data is complete for many operational modes for NOx and CO and partial data exists for PM emissions. THC emissions were taken with grab samples, which are expected to be underestimate emissions. Engines were tested at many different load points from cruise to idle.

Table 1-9 displays the engines sampled for emissions with the engine specifications gleaned from MER (2001). All engines were either Category 1 or 2 medium-speed engines or a turbine engine, which defies categorization. So coupled with Lloyds (1995) data described above, the EPA (2000) report relied on data from engines that do not fit the Category 3 classifications.

Table 1-9. Engine specifications from ETC (1997).

Vessel	Engine	Engine Type	Rated Power (kW)	Vessel Type	Speed (rpm)	Bore (mm)	Stroke (mm)	Displacement (l/cylinder)	Category
Steadfast	Alco 16V-251-B	Diesel	1864	Cutter	1000	229	267	11	2
Sherman	Faibanks-Morse 3800 TD 8 1/8	Diesel	2610	Cutter	900	206	254	8	2
Sherman	Pratt – Whitney	Turbine	13423	Cutter	-	-	-	-	-
Tybee	Paxman Type 16 RP 200M Valenta V-16	Diesel	2148	Cutter	1500	197	216	7	2
Long Island	Caterpillar 3516 DITA V Type	Diesel	2036	Cutter	1910	170	190	4	1
Thetis	Alco V-18 251-C	Diesel	2722	Cutter	1025	229	267	11	2
41 ft UTB	Cummins VT-903M	Diesel	237	Utility Boat	2300	140	152	2	1

Lloyds (1997); Environment Canada (1999)

These two reports detailed the same emissions data, so the discussion here combines the two reports as one study. This study investigated emissions found on ferries but produced emission estimates only in units of kg/tonne for two operating modes (idle, and full power). As shown in Table 1-10, all three engine categories were included in the test program. Of the Category 3 engines, only medium speed engines were included.

Table 1-10. Diesel engine specifications from Lloyds (1997) from information supplied by Environment Canada (1999).

Engine	Power (kW)	Type	Speed (rpm)	Bore (mm)	Stroke (mm)	Displacement (l/cylinder)	Category
MAK 12M551AK	3430	Ferry	500	450	520	83	3
Wartsilla 9R32D	2535	Ferry	750	320	350	28	2
MAK9MU551AK	3024	Ferry	500	450	520	83	3
Mirlees VSSM*	2490	Ferry	381	457	320	52	3
Mitsubishi S12R**	800	Ferry	1534	160	180	4	1
Bergen KRGB9	1800	Ferry	900	250	300	15	2
Engine 1: Caterpillar 3412	242	Ferry	1600	137	152	2	1
Engine 2: Caterpillar 3412	242	Ferry	1600	137	152	2	1
MAN 6C40/54	2807	Ferry	550	400	540	68	3
Waukesha F2896	242	Auxiliary	1020	216	216	8	2
Mitsubishi***	221	Auxiliary	1210	240	260	12	2
Caterpillar 398	164	Auxiliary	1205	159	203	4	1

* Assumed to be the K Major design based on reported rated power and speed.

** Assumed to be the SM design based on reported rated power and speed.

*** Assumed to be the SU design based on reported rated power and speed.

Environment Canada (1997)

This study performed by Environment Canada investigated emissions measured on vessels producing emission estimates only in units of kg/tonne. The THC emissions were collected using grab samples using bags or other collection devices. This type of sampling is known to under represent average emission rates because the walls of the collection device allows heavier hydrocarbons to condense.

In Table 1-11 are the engine specifications determined from the engine model and MER (2001). This was a large data source for slow speed engines with some Category 3 medium-speed engines as well.

Table 1-11. Engine specifications for Environment Canada (1997).

Engine	Year	Power		Type	Bore Stroke Displacement			Category	Speed (rpm)	
		(kW)			Stroke(mm)	(mm)	(l/cylinder)			
Sulzer 7RTA 52U	1996	11066		Cargo	2	520	1800	382	3	98 - 135
K MAN K7SZ70/125	1978	9918		Cargo	2	700	2674	1029	3	68 - 91
M MAN 5S60MC	1992	9508		Cargo	2	600	2292	648	3	79 - 105
Sulzer RND90	1980	22371		Cargo	2	900	1900	1209	3	90 - 101
Sulzer RND90	1980	22371		Cargo	2	900	1900	1209	3	90 - 101
K MAN 10L90MC MKD	1997	43699		Container	2	900	2916	1855	3	62 - 82
K MAN 10L90MC MKD	1997	43699		Container	2	900	2916	1855	3	62 - 82
Sulzer 9RTA 84C	1991	33557		Container	2	840	2400	1330	3	73 - 102
B&W Mitsui 7K67GF*	1978	9769		Cargo	2	670	1700	599	3	123
DDC Series 149 t	1986	895		Tug	4	146	146	2	1	1900
MAK 12M551AK	1976	4362		Ferry	4	450	520	83	3	500
3xMAN B&W 7L23/30H		922		Auxiliary	4	225	300	12	2	825 - 900
3xBergen KRG-6		1074		Auxiliary	4	250	300	15	2	720 - 900
Sulzer V12 12ZAV40	1995	8752		Cruise**	4	400	560	70	3	510
3xWaukesha F2896		608		Auxiliary	4	216	216	8	2	600-1215
Sulzer V12 12ZAV40	1991	8752		Cruise**	4	400	560	70	3	510

* Mitsui never produced a slow speed "67" model but B&W MAN did, so B&W MAN engine specifications are provided.

** These engines were listed as both propulsion and auxiliary engines, so presumably these vessels used diesel-electric drives.

TRC (1989)

Data in this study included emission estimates only in kg/tonne for auxiliary engines with engine rating less than 2,000 kW. Data existed on steamship emission rates also in kg/tonne units for hotelling emissions from both auxiliary and main boilers. But no information about the engines was available other than rated powers, which were all under 2,000 kW, and therefore were considered Category 2 engines as described above for the Lloyds (1995). A table of the engine specifications therefore could not be created.

EMISSION RATE RECOMMENDED AVERAGES

For recommending emission factors for Category 3 marine engines, the emissions data was separated into different categories by displacement (to distinguish between Category 2 and 3 engines) and by engine speed (above or below 300 rpm) for Category 3 engines before determining average emissions estimates. The reason for distinguishing these categories was that historical data (Lloyds, 1995) had demonstrated that slow speed engines produced higher NO_x emissions than medium speed engines. Also, the purpose of this assignment was to review Category 3 engine emission factors separate of other engine types.

The intention of this work was to include as much of the available accurate data as possible in determining the average emission rates. Because the greatest number of engines were tested at the load of the service speed (i.e. during the cruise mode) of the vessel, this highest load point was used to compute an average emission rate for all similar types of engines. Emission rate averages were determined first in units of kg/tonne and converted with the average of the available information on fuel efficiency. Another reason for using the load point at the service speed was that EPA (2000) found that the emissions rates and fuel efficiency of engines becomes less (or not at all) a function of load for loads above about 20%, so the test point on one engine could be considered equivalent to another.

For slow speed engines, those under 300 rpm which are typically direct-drive, the average emission estimates are shown in Table 1-12. Of note here was the influence of the two K MAN engines with extraordinary NO_x emission rates raising the average from 97.7 to 107.8 kg/tonne, but there was no reason determined to exclude this data. Also, these results compare with the reported average values from Lloyds (1995) for these types of engines of 87 (kg/tonne) of NO_x converted to 17 (g/kW-hr) with a fuel efficiency of 0.195 (kg/kW-hr). The Lloyds (1995) estimate represents a lower range of a possible emission factor to be demonstrated in the sensitivity analysis in a later chapter.

Table 1-12. Summary data for category 3 slow speed engines at maximum operating point tested.

Study	Vessel (Year)	Engine	Speed (rpm)	Percent Power*	BSFC (kg/kW-hr)	NO _x (kg/tonne)	CO (kg/tonne)	PM (kg/tonne)
Lloyds (1995)	R8port (1980)	NA	155		0.221	105.6		
Lloyds (1995)	R8stbd (1980)	NA	155		0.221	110.2		
Lloyds (1995)	R9port (1980)	NA	153		0.225	86.4		
Lloyds (1995)	R9stbd (1980)	NA	155		0.194	115.9		
Lloyds (1995)	TK6 (1970)	NA	131		0.243	58.0		
Lloyds (1995)	TK9 (1977)	NA	110		0.208	123.2		
Env. C. (1997)	(1996)	Sulzer 7RTA 52U	125	93%		84.8		6.24
Env. C. (1997)	(1978)	K MAN K7SZ70/125	135	93%		99.3	9.7	6.4
Env. C. (1997)	(1992)	M MAN 5S60MC	90	99%		51.7	5.02	7.43
Env. C. (1997)	(1980)	Sulzer RND90	117	87%		83.6	1.45	1.04
Env. C. (1997)	(1980)	Sulzer RND90	116	86%		120.1	6.7	10.49
Env. C. (1997)	(1997)	K MAN 10L90MC MKD	75	67%		178.9	5.51	16.32
Env. C. (1997)	(1997)	K MAN 10L90MC MKD	79	77%		168.1	4.72	11.84
Env. C. (1997)	(1991)	Sulzer 9RTA 84C	95	84%		119.5	3.5	8.03
Env. C. (1997)	(1978)	B&W Mitsui 7K67GF	122	70%		111.3	3.94	4.9

Average	121	84%	0.219	107.8	5.1	8.1
Average (g/kW-hr)				23.6	1.1	1.8

* Percent of rated power at cruise.

Trade literature and manufacturers claims of specific fuel consumption rate and emissions levels have been reported to be much lower than the data in Table 1-12 indicate. The trade journal *The Motor Ship* (1999) reported that a Wartsila NSD engine has fuel efficiency of ~165 g/kW-hr and produces NO_x at 17 g/kW-hr while a MAN B&W engine has fuel efficiency of ~190 g/kW-hr and produces NO_x at 18.6 g/kW-hr. These engines then both produce NO_x at levels at about 100 kg/tonne or close to the average determined from the data shown above. The specific fuel consumption rate in the measured data reported specifically for those engine models shown above is significantly higher than that reported by the manufacturers as between 160 - 179 g/kW-hr (MER, 1999). Because the emissions data was measured in kg/tonne units, the specific fuel consumption was an important estimate in determining the specific emission rate. However for this work, the measured data was used to estimate specific emission rates rather than the manufacturer's reported estimates because the measured data was better understood. But further investigation is needed to reconcile this conflict in the fuel consumption rate estimates.

For medium speed Category 3 engines, the results are shown in Table 1-13. These results have higher emissions rates than the reported average values from Lloyds (1995) for these types of engines of 57 (kg/tonne) of NO_x converted to 12 (g/kW-hr) with a fuel efficiency of 0.211 (kg/kW-hr). However, as described above, the Lloyds results did not distinguish between small and large displacement medium speed engines. Table 1-14 shows that the NO_x emission results for Category 2 medium speed engines indicate a much closer correlation with the Lloyds (1995) averages indicating that the medium speed average reported by Lloyds (1995) was primarily influenced by smaller displacement engines. The difference between emission rates for Category 2 and 3 medium speed engines is considered sufficiently significant to recommend separate emission rates.

Table 1-13. Summary data for category 3 medium speed engines at maximum operating point tested.

Study	Vessel (Year) Engine		Speed (rpm)	BSFC (kg/kW-hr)	NO_x (kg/tonne)	CO (kg/tonne)	PM (kg/tonne)
Lloyds (1995)	B5 (1986)	NA	595	0.219	70.71		
Lloyds (1995)	D1 (1975)	NA	600	0.200	65.32		
Lloyds (1995)	R2port (1987)	NA	510	0.269	80.44		
Lloyds (1995)	R3port (1978)	NA	512	0.224	71.97		
Lloyds (1995)	R3stbd (1978)	NA	520	0.224	70.54		
Lloyds (1995)	R4 (1978)	NA	570	0.233	55.11		
Lloyds (1995)	R7port (1987)	NA	510	0.220	81.69		
Lloyds (1995)	TK3 (1978)	NA	450	0.235	50.52		
Lloyds (1995)	R2cent (1987)	NA	510	0.220	75.69		
Env. C. (1997)	(1976)	MaK 12M551AK	500		82.79		6.64
Env. C. (1997)	(1995)	Sulzer V12 12ZAV40	510		86.22	4.07	0.65
Env. C. (1997)	(1991)	Sulzer V12 12ZAV40	510		76.28	3.04	5.53
Env. C. (1999)	Not reported	MaK 12M551AK	500	0.212	69.9	1.8	1.1
Env. C. (1999)	Not reported	Wartsilla 9R32D*	750*	0.212	78.9	2.5	2.8

Study	Vessel (Year)	Engine	Speed (rpm)	BSFC (kg/kW-hr)	NOx (kg/tonne)	CO (kg/tonne)	PM (kg/tonne)
Env. C. (1999)	Not reported	MaK9MU551AK	500	0.244	104.3	4.2	0.9
Env. C. (1999)	Not reported	Mirlees VSSM	600	0.220	72.6	3.0	3.0
Env. C. (1999)	Not reported	MAN 6C40/54	550	0.176	79.6	3.6	4.4
Average			540	0.222	74.9	3.2	3.1
Average (g/kW-hr)					16.6	0.7	0.7

* This engine has a displacement of 28 l/cylinder, close to Category 3 but technically a Category 2 engine.

The PM emission rates in the Tables 1-13 and 1-14 show considerable variability, which are probably explained by the fuel sulfur level during the test. Lloyds (1995) compared the PM emission rates for different fuel sulfur levels and are shown in Figure 1-1. For comparison to the data, the sulfate-related PM was calculated using equations found in EPA (1998) and shown as the dotted line in Figure 1-1. This calculated sulfate PM uses the estimate that 2.2% of the fuel sulfur directly converts in the engine to $H_2SO_4 \cdot 7H_2O$, and explains much of the increased PM with higher fuel sulfur level fuels in the data. The fuel sulfur level needs to be specified in order to estimate the emission factor from commercial marine engines according to the best-fit estimate in Figure 1-1. While the best fit to the data indicates an exponential function with fuel sulfur, this nonlinear fit may be an artifact of the data set used to determine this fit.

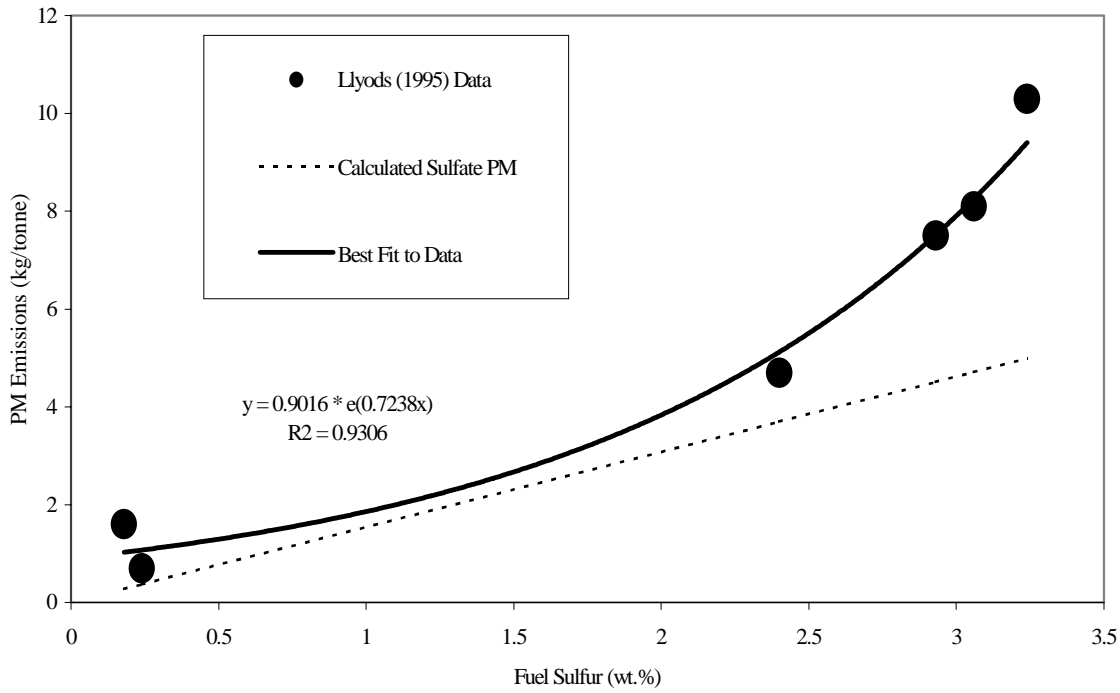


Figure 1-1. Effect of fuel sulfur on particulate emissions rates.

The available data for smaller engines, likely Category 2, were available for comparison with the Category 3 results. The Category 2 data shown in Table 1-14 was taken on 4-stroke medium and high speed engines and the average computed indicates that the Category 2 NOx emissions were found to be significantly lower than the Category 3 NOx emission rates in equivalent units.

Table 1-14. Summary data for category 2 medium speed engines.

Study	Vessel	Engine	Use	NOx (kg/tonne)
Env. Canada (1999)	N/A	Bergen KRGB9	Propulsion	40.60
Env. Canada (1999)	N/A	Engine 1: Caterpillar 3412	Propulsion	54.40
Env. Canada (1999)	N/A	Engine 2: Caterpillar 3412	Propulsion	44.90
Env. Canada (1999)	N/A	Waukesha F2896	Auxiliary	47.70
Env. Canada (1999)	N/A	Mitsubishi	Auxiliary	98.70
Env. Canada (1997)	N/A	3 x MAN B&W 7L23/30 H	Auxiliary	24.44
Env. Canada (1997)	N/A	3 x Bergen KRG-6	Auxiliary	43.69
Env. Canada (1997)	N/A	3 x Waukesha F2896 DSIM	Auxiliary	36.74
ETC (1997)	Steadfast	Alco 16V-251-B (Starboard)	Propulsion	81.51
ETC (1997)	Steadfast	Alco 16V-251-B (Port)	Propulsion	62.56
ETC (1997)	Sherman	Faibanks-Morse 3800 TD 8 1/8, 12Cy (starboard)	Propulsion	42.50

Study	Vessel	Engine	Use	NOx (kg/tonne)
ETC (1997)	Sherman	Faibanks-Morse 3800 TD 8 1/8, 12Cy (Port)	Propulsion	44.90
ETC (1997)	Tybee	Paxman Type 16 RP 200M Valenta V-16 (starboard)	Propulsion	39.01
ETC (1997)	Tybee	Paxman Type 16 RP 200M Valenta V-16 (port)	Propulsion	38.27
ETC (1997)	Thetis	Alco V-18 251-C (starboard)	Propulsion	48.58
ETC (1997)	Thetis	Alco V-18 251-C (port)	Propulsion	47.29
TRC (1989)	President Adams	N/A	Auxiliary	59.94
TRC (1989)	President Adams	N/A	Auxiliary	56.09
TRC (1989)	Madame Butterfly	N/A	Auxiliary	74.91
TRC (1989)	Spring Bride	N/A	Auxiliary	92.68
TRC (1989)	Beltimber	N/A	Auxiliary	44.97
TRC (1989)	President Washington	N/A	Auxiliary	35.54
TRC (1989)	Hyundai Challenger	N/A	Auxiliary	50.53
TRC (1989)	California Jupiter	N/A	Auxiliary	51.34
TRC (1989)	Manhattan Bridge	N/A	Auxiliary	72.27
TRC (1989)	National Dignity	N/A	Auxiliary	18.14
TRC (1989)	Evergroup	N/A	Auxiliary	36.05
TRC (1989)	Sealand Explorer	N/A	Auxiliary	79.25
TRC (1989)	Aurora Ace	N/A	Auxiliary	52.94
TRC (1989)	Thorseggen	N/A	Auxiliary	100.58
TRC (1989)	Walter Jacob	N/A	Auxiliary	64.37
TRC (1989)	Star Esperanza	N/A	Auxiliary	47.28
TRC (1989)	Dynachem	N/A	Auxiliary	42.17
Lloyds (1995)	R7gen	N/A	Auxiliary	52.88
Lloyds (1995)	TK5	N/A	Propulsion	60.21
Lloyds (1995)	TG1push	N/A	Propulsion	56.96
Lloyds (1995)	TG6push	N/A	Propulsion	61.22
Lloyds (1995)	R7cent	N/A	Propulsion	52.88
Lloyds (1995)	TK1	N/A	Propulsion	58.79
Lloyds (1995)	TG3frun	N/A	Propulsion	51.76
Average				54.2

The THC emissions data was not well characterized in these studies, so the average emissions rate is recommended to be the Lloyds (1995) average, 2.4 (kg/tonne) converted to 0.53 g/kW-hr, where emissions were determined at the stack and did not rely on grab samples.

At loads below 20%, the relative emissions (in g/kW-hr units) and fuel consumption may be higher as indicated by EPA (2000), and slow and medium speed emission factors were adjusted as described here. At low loads there was evidence (EPA, 2000) described in Chapter 1 that specific emissions (in g/kW-hr units) at low loads could increase markedly compared with the high load emission rates used in this work. In order to estimate this effect, the ratio in emissions levels at 10% load (maneuvering load) compared to the loads used in the cruise emission rates 84% load for slow speed (the cruise speed average load) and 99% load for medium speed engines (cruise speed load especially with ferry engines) were determined from with results as shown in Table 1-15. As the load decreases, one expects specific (relative to shaft work in kW-hr) emissions to increase as parasitic loads (loads which do not produce shaft work) become a greater fraction of the engine work.

Table 1-15. Ratio of maneuvering emissions factors at 10% load to full load emission rates used in this sensitivity analysis.

Pollutant	Slow Speed Engines	Medium Speed Engines
HC	5.28	5.50
CO	8.52	7.41
NO _x	1.36	1.36
PM	1.69	1.68
SO ₂	1.57	1.55

STEAMSHIP EMISSIONS

The data for steamship emissions was available only during hotelling operation, while emissions will be primarily calculated for transit operation. As shown in Table 1-16, the data and EPA guidance were similar, so the official EPA guidance is recommended for steamship emission rates.

Table 1-16. Hotelling emission factors for steamships.

Engine/Boiler Type	NO_x (kg/tonne)	HC (kg/tonne)	CO (kg/tonne)	PM (kg/tonne)
Main Boilers TRC (1989)	9.8	-	0.4	-
Smaller Boilers TRC (1989)	12.3	N/A	4.6	N/A
EPA Guidance (BAH, 1991)	8.1 (2.8 g/kW-hr)	0.2 (0.07 g/kW-hr)	0.9 (0.3 g/kW-hr)	7.2 (2.5 g/kW-hr)

* For emissions rates labeled N/A, EPA guidance was used.

In order to use the emission rates, the emission factor needs to be converted to units of g/kW-hr through a fuel efficiency estimate. BAH (1991) provides estimates of daily fuel consumption at full power and average power for steamships of dead weight tonnage (DWT) 50 – 75 kton and 75 – 100 kton. Using the BAH (1991) estimate that full power constitutes 80% of installed power, the calculated fuel efficiency for steamships was 0.350 and 0.334 (kg/kW-hr) for the two DWT ranges. Using the average fuel efficiency of 0.342 (kg/kW-hr), the recommended emission rates are shown in Table 1-16 for steamships. The steamships are being retired, so errors in this emission rate will have less effect on the overall emissions inventory with future year predictions.

2. PORT MATCHING

INTRODUCTION

The purpose of this chapter is to describe the matching criteria used to associate ports that have detailed ship information (such as installed power, cruise speed, and hotelling hours per call) with those without such information. With the results of this work, it was possible to define the typical ship size and therefore the installed engine power for any port according to the procedure outlined in Arcadis (1999a and 1999b) and also described in Chapter 3. This procedure provides a method for using ratios in general vessel calls between like ports to estimate vessel activity at ports where only general vessel activity was available. Vessel characteristics were available for some detailed ports, which could be used at other ports matched to these ports. It was important to match the best estimate of detailed vessel characteristics to ports where such vessels would likely be operating. The detailed ports average vessel characteristics were then matched to other ports, with the total number of vessel calls by ship type determined by the ratio of overall vessel calls.

There were two criteria involved in port matching: regional differences and maximum vessel draft. The first cut used general geographical area to group the top ports into four regions: the Pacific Coast, the Atlantic Coast, the Gulf Coast, and the Great Lakes. This followed the assumption that the geographical area of a port was a primary influence on the characteristics (mainly size and installed power) of vessels calling these ports. The service for each of these regions was also likely unique in terms of the foreign or domestic previous and next ports of call, which is another factor affecting the type of vessel calling on each port in light of regional competition for business. In each of the four regions, there were at least two “typical ports” with detailed activity information in the EPA documents (Arcadis, 1999a and 1999b). The top deep sea and Great Lake ports without detailed activity information were then each matched to a typical port in the same region based on the maximum vessel draft of ships that entered the port during the given year (1996). Maximum vessel draft was assumed to correlate to the size of a vessel, and the size was considered to correspond to the horsepower of the vessel engines within each vessel type. In cases where more than one typical port in a given region had the same maximum vessel draft, geographical area was again the deciding factor for the ports that matched to that value. The port and its matched typical port were then assumed to have many of the same vessel activity patterns, including engine power breakdown by vessel type, vessel speed, and time in modes. Once matched, the number of vessel calls by vessel type were appropriately scaled for those ports without the specific call information using data that was gathered for the detailed ports.

RESULTS

This work resulted in tables of matched ports by region based on the criteria described above. The port matching was executed for the top ports available in the 1996 and 1999 USACE (2001) data, which were not necessarily the same as the top ports provided in the Arcadis work (1999a and 1999b) based on 1995 vessel call information. But the 1995 vessel call information was used for determining the activity of the matched ports described in Chapter 3.

The available detailed deep-sea port information from Arcadis (1999a and 1999b) often included vessel calls for several ports combined. For the detailed ports constituted of several ports, average or typical characteristics were used to determine the matching described below. Shown below in Table 2-1 are the individual ports included in the deep-sea detailed ports and maximum drafts for vessels at those ports.

Table 2-1. Ports included in each detailed deep-sea port to be matched with other ports.

Waterway	Port Name	Max Draft (ft)	Region *	Detailed Port
0700	Baltimore, MD	48	A	Maryland MEPA
0398	New York, NY and NJ	48	A	Port of New York MEPA
0297	Chester, PA	43	A	Philadelphia MEPA
0298	Penn Manor, PA	43	A	Philadelphia MEPA
0299	New Castle, DE	43	A	Philadelphia MEPA
0552	Philadelphia, PA	43	A	Philadelphia MEPA
5251	Marcus Hook, PA	43	A	Philadelphia MEPA
5252	Paulsboro, NJ	43	A	Philadelphia MEPA
0551	Camden, NJ	41	A	Philadelphia MEPA
0554	Wilmington, DE	41	A	Philadelphia MEPA
2251	New Orleans, LA	48	G	New Orleans MEPA
2253	South Louisiana, LA	48	G	New Orleans MEPA
2255	Plaquemine, LA	48	G	New Orleans MEPA
2252	Baton Rouge, LA	43	G	New Orleans MEPA
2423	Corpus Christi, TX	45	G	Corpus Christi MEPA
2021	Tampa, FL	39	G	Tampa MEPA
4702	Grays Harbor, WA	36	P	Puget Sound MEPA
4708	Port Angeles, WA	52	P	Puget Sound MEPA
4730	Anacortes, WA	50	P	Puget Sound MEPA
4720	Tacoma, WA	45	P	Puget Sound MEPA
4725	Everett, WA	39	P	Puget Sound MEPA
4722	Seattle, WA	38	P	Puget Sound MEPA
4718	Olympia, WA	33	P	Puget Sound MEPA
4732	Bellingham, WA	33	P	Puget Sound MEPA
4660	Coos Bay, OR	38	P	Columbia River MEPA

* Key; A = Atlantic Coast, G = Gulf Coast, P = Pacific Coast

The summary of the matching for the Atlantic Coast ports is shown in Table 2-2. The detailed data from Philadelphia would be primarily used because the other detailed ports, Maryland and New York, represented the ability to receive greater vessel drafts. The maximum draft of the Philadelphia ports was 43 feet, an already larger vessel draft than many ports can receive. Thus, the ports with smaller draft, some as low as 15-foot draft, likely will be associated with larger vessels than could normally call on these ports. Other work might investigate whether the maximum draft can be associated with maximum dead-weight tonnage to avoid using oversized vessels in the emissions calculations for the lower draft ports. A remedy for this issue is to determine detailed vessel information for one or more smaller and shallow draft ports more similar to other smaller ports.

Table 2-2. Summary of the Atlantic Coast deep-sea ports and the matched detailed port.

Waterway	Port Name	Max Draft (ft)	Region	Detailed Port Matched To
0128	Portland, ME	46	A	Port of New York MEPA
0736	Newport News, VA	49	A	Maryland MEPA
0776	Savannah, GA	46	A	Maryland MEPA
5735	Norfolk, VA	50	A	Maryland MEPA
0110	Bucksport, ME	34	A	Philadelphia MEPA
0112	Searsport, ME	35	A	Philadelphia MEPA
0135	Portsmouth, NH	37	A	Philadelphia MEPA
0146	Salem, MA	35	A	Philadelphia MEPA
0149	Boston, MA	41	A	Philadelphia MEPA
0189	Fall River, MA	36	A	Philadelphia MEPA
0191	Providence, RI	39	A	Philadelphia MEPA
0311	Bridgeport, CT	38	A	Philadelphia MEPA
0317	Stamford, CT	15	A	Philadelphia MEPA
0522	Port Jefferson, NY	33	A	Philadelphia MEPA
0737	Richmond, VA	22	A	Philadelphia MEPA
0738	Hopewell, VA	27	A	Philadelphia MEPA
0764	Morehead City, NC	34	A	Philadelphia MEPA
0766	Wilmington, NC	38	A	Philadelphia MEPA
0772	Georgetown, SC	28	A	Philadelphia MEPA
0773	Charleston, SC	42	A	Philadelphia MEPA
0780	Brunswick, GA	35	A	Philadelphia MEPA
1507	New Haven, CT	38	A	Philadelphia MEPA
2017	Jacksonville, FL	40	A	Philadelphia MEPA
2136	San Juan, PR	41	A	Philadelphia MEPA
2160	Canaveral, FL	37	A	Philadelphia MEPA
2162	Palm Beach, FL	33	A	Philadelphia MEPA
2164	Miami, FL	41	A	Philadelphia MEPA
2139	Fajardo, PR	32	A	Philadelphia MEPA
2151	Ponce, PR	31	A	Philadelphia MEPA
3303	Trenton, NJ	20	A	Philadelphia MEPA

Table 2-3 shows the matched ports for the Gulf Coast. Again there is the potential problem with ports associated with the detailed port of Tampa, where the maximum draft was 39 feet. Tampa represents the available detailed port with the smallest maximum vessel draft, but its vessel sizes are still much larger than some other ports can realistically handle. Also noted here is that a detailed study of the Houston area ports (Starcrest, 2000) was used instead of the general methodology, so no port association was needed for those four ports covered by this work.

Table 2-3. Summary of the Gulf Coast deep-sea ports and the matched detailed port

Waterway	Port Name	Max Draft (ft)	Region	Typical Port Matched To
2002	Biloxi, MS	15	G	Tampa MEPA
2004	Pascagoula, MS	38	G	Tampa MEPA
2005	Mobile, AL	43	G	Corpus Christi MEPA
2007	Pensacola, FL	33	G	Tampa MEPA
2012	Houston, TX	44	G	Starcrest (2000)
2016	Panama City, FL	31	G	Tampa MEPA
2083	Gulfport, MS	32	G	Tampa MEPA
2163	Port Everglades, FL	47	G	New Orleans MEPA
2167	Weedon Island, FL	30	G	Tampa MEPA
2254	Lake Charles, LA	43	G	Corpus Christi MEPA
2395	Beaumont, TX	43	G	Corpus Christi MEPA
2404	Texas City, TX	44	G	Starcrest (2000)
2408	Freeport, TX	42	G	Starcrest (2000)
2410	Matagorda Ship	37	G	Tampa MEPA
2411	Victoria, TX	12	G	Tampa MEPA
2416	Port Arthur, TX	40	G	Tampa MEPA
2417	Galveston, TX	42	G	Starcrest (2000)
2420	Brownsville, TX	36	G	Tampa MEPA
2116	Charlotte, FL	28	G	Tampa MEPA

The California ports, for which the Air Resources Board produced emission estimates, dominate the Pacific Coast ports. Also, other work (Arcadis, 1999c) prepared vessel activity and emissions estimates for the Ports of Los Angeles and Long Beach, which may be included in the expected ARB data.

A concern for other port matching with following the strict criteria described was that the Puget Sound MEPA data was considered applicable only for maximum vessel drafts of 52 feet based on the draft at Port Angeles or 50 feet at the Port of Anacortes. This 52 feet maximum vessel draft for the Puget Sound MEPA data was considered unrepresentative of the typical vessels calling on the Puget Sound because the bulk of the vessels in the Puget Sound were those calling the Port of Seattle (~60% of vessel calls) with a vessel draft of 38 feet and the Port of Tacoma (~20% of vessel calls) with a vessel draft of 45 feet. The deep draft ports within the Puget Sound MEPA, Port Angeles and Anacortes, accounted for only a small

fraction of all vessel calls (~12%) in the Puget Sound MEPA data. Therefore, it was determined that non-California Pacific Coast ports with vessel drafts greater than 38 feet, especially the Columbia River ports of Kalama, Longview, Vancouver, and Portland, be associated with the Puget Sound MEPA data rather than the port of Coos Bay. The Pacific Coast port matching is shown in Table 2-4.

Table 2-4. Summary of the Pacific Coast deep-sea ports and the matched detailed port

WTWY	Port Name	Max Draft (ft)	Region	Typical Port Matched To
4100	San Diego, CA	40	P	Separate CARB-supplied Data
4110	Long Beach, CA	58	P	Separate CARB-supplied Data
4120	Los Angeles, CA	51	P	Separate CARB-supplied Data
4150	Port Hueneme, CA	35	P	Separate CARB-supplied Data
4240	Sacramento, CA	33	P	Separate CARB-supplied Data
4270	Stockton, CA	32	P	Separate CARB-supplied Data
4335	San Francisco, CA	49	P	Separate CARB-supplied Data
4340	Redwood City, CA	33	P	Separate CARB-supplied Data
4345	Oakland, CA	38	P	Separate CARB-supplied Data
4350	Richmond, CA	49	P	Separate CARB-supplied Data
4375	Humboldt, CA	34	P	Separate CARB-supplied Data
4400	Hilo, HI	32	P	Columbia River MEPA
4405	Kawaihae, HI	19	P	Columbia River MEPA
4410	Kahului, Maui, HI	34	P	Columbia River MEPA
4420	Honolulu, HI	40	P	Puget Sound MEPA
4430	Nawiliwili, Kauai, HI	33	P	Columbia River MEPA
4457	Barbers Point, HI	55	P	Puget Sound MEPA
4622	Longview, WA	40	P	Puget Sound MEPA
4626	Kalama, WA	42	P	Puget Sound MEPA
4636	Vancouver, WA	40	P	Puget Sound MEPA
4644	Portland, OR	40	P	Puget Sound MEPA
4800	Ketchikan, AK	37	P	Puget Sound MEPA
4816	Valdez, AK	72	P	Puget Sound MEPA
4820	Anchorage, AK	36	P	Columbia River MEPA
4831	Nikishka, AK	39	P	Columbia River MEPA
4978	Kivilina, AK	20	P	Columbia River MEPA

The Great Lakes port matching shown in Table 2-5 was straight-forward using the criteria described though the maximum vessel draft for Burns Harbor (28 feet) and Cleveland (29 feet) are nearly indistinguishable (see Table 2-5).

Table 2-5. Summary of the Great Lakes ports and the matched detailed port

Waterway	Port Name	Max Draft (ft)	Matched to 1996 Typical Port
3924	Duluth-Superior, MN & WI	29	Cleveland Harbor, OH
3749	Port of Chicago, IL	28	Burns Waterway Harbor, IN
3738	Indiana Harbor, IN	31	Cleveland Harbor, OH
3321	Port of Detroit, MI	29	Cleveland Harbor, OH
3216	Lorain Harbor, OH	29	Cleveland Harbor, OH
3204	Toledo Harbor, OH	30	Cleveland Harbor, OH
3845	Presque Isle Harbor, MI	29	Cleveland Harbor, OH
3219	Ashtabula Harbor, OH	31	Cleveland Harbor, OH
3736	Gary Harbor, IN	29	Cleveland Harbor, OH
3929	Taconite Harbor, MN	29	Cleveland Harbor, OH
3795	Escanaba, MI	31	Cleveland Harbor, OH
3619	Stoneport, MI	28	Burns Waterway Harbor, IN
3620	Calcite, MI	28	Burns Waterway Harbor, IN
3926	Two Harbors, MN	29	Cleveland Harbor, OH
3501	St. Clair, MI	30	Cleveland Harbor, OH
3220	Conneaut Harbor, OH	30	Cleveland Harbor, OH
3803	Port Inland, MI	28	Burns Waterway Harbor, IN
3928	Silver Bay, MN	29	Cleveland Harbor, OH
3506	MarineCity, MI	29	Cleveland Harbor, OH
3213	Sandusky Harbor, OH	29	Cleveland Harbor, OH
3212	Marblehead, OH	26	Burns Waterway Harbor, IN
3756	Milwaukee Harbor, WI	28	Burns Waterway Harbor, IN
3627	Port Dolomite, MI	28	Burns Waterway Harbor, IN
3218	Fairport Harbor, OH	27	Burns Waterway Harbor, IN
3617	Alpena Harbor, MI	27	Burns Waterway Harbor, IN
3778	Green Bay Harbor, WI	26	Burns Waterway Harbor, IN
3202	Monroe Harbor, MI	28	Burns Waterway Harbor, IN
3230	Port of Buffalo, NY	27	Burns Waterway Harbor, IN
3725	Muskegon Harbor, MI	28	Burns Waterway Harbor, IN
3813	Drummond Island, MI	27	Burns Waterway Harbor, IN
3706	Charlevoix Harbor, MI	22	Burns Waterway Harbor, IN
3737	Buffington Harbor, IN	27	Burns Waterway Harbor, IN
3722	Ludington Harbor, MI	30	Cleveland Harbor, OH
3214	Huron Harbor, OH	28	Burns Waterway Harbor, IN
3221	Erie Harbor, PA	28	Burns Waterway Harbor, IN
3726	Grand Haven Harbor, MI	25	Burns Waterway Harbor, IN

3. 1996 EMISSIONS ESTIMATES AND CALCULATION PROCEDURE**INTRODUCTION AND SUMMARY**

This chapter describes estimates of the national emissions inventory for the US ports from activity of merchant vessels and other ships that use Category 3 engines. The emissions from the activity of merchant vessels in the United States were determined by ship type and by each of four modes of operation (cruise, reduced speed zone (RSZ), maneuvering, and hotelling). These four modes encompass merchant vessel activity out 25 nautical miles from ocean coasts and 10 nautical miles from Great Lakes' coasts. The propulsion power for these ships was supplied predominately by Category 3 2-stroke diesel engines with some Category 3 4-stroke and steamship engines, and auxiliary power was typically supplied by Category 2 or smaller 4-stroke diesel engines.

Summaries are provided in Tables 3-1 and 3-2 of all merchant vessels including those propelled by motor and steam ships excluding vessel types that likely use only smaller propulsion engines than Category 3, excluding vessels such as barge carriers, fishing, and supply vessels. The data used to determine vessel activity and vessel characteristics (overall engine power, vessel speed, hotelling times, etc.) was provided in earlier EPA contracted work (Arcadis, 1999a and 1999b).

Table 3-1. Summary of the US emission estimates by ship type (tons/year).

Ship Type	HC	CO	NO_x	PM	SO₂
Bulk Carrier (BC)	1,461	5,906	45,196	2,668	18,812
Container Ship (CS)	2,360	5,797	38,404	3,125	23,881
General Cargo (GC)	478	2,060	16,078	996	6,940
Miscellaneous (OT)	179	1,066	5,914	245	1,552
Passenger (PA)	344	879	6,143	747	5,804
Reefer (RF)	257	756	4,160	263	1,952
Roll-on roll-off (RO)	140	567	4,830	421	3,114
Tanker (TA)	1,175	3,950	32,022	3,048	22,507
Vehicle Carrier (VC)	259	570	3,732	293	2,247
Total	6,650	21,529	156,478	11,794	86,763

Table 3-2. Summary of the US emission estimates by mode (tons/year).

Mode Type	HC	CO	NO_x	PM	SO₂
Cruise	739	1,484	31,423	2,909	21,894
RSZ	2,587	4,635	58,707	5,215	39,936
Maneuvering	1,762	4,726	7,120	895	4,912
Hotelling	1,563	10,685	59,219	2,774	19,925
Total	6,650	21,529	156,478	11,794	86,763

The propulsion engines of the vessels included in the Arcadis (1999c) data were considered to be

Category 3 engines with the exception of the steamships. The auxiliary generator engines used during hotelling (also called dwelling or berthing) are not likely Category 3 engines except for some generators on specific types of vessels that require high electrical loads, such as some refrigerated cargo (reefers) and cruise ships. Because the Category 3 engines are used for propulsion, the transit (cruise, RSZ, and maneuvering) emission totals most closely represent the Category 3 emission estimates for vessels calling on US ports. The cruise, reduce speed zone (RSZ), maneuvering, and hotelling totals are shown by ship type in Tables 3-3 through 3-6. All transit emissions but only a small part of the hotelling should be considered as derived from Category 3 engines. While steamship emissions do not fit into the diesel engine categorization, ships that use steam propulsion systems will likely be retired, and vessels with diesel engines will be eventually nearly entirely replace steamships.

Table 3-3. Cruise (to and from 25 miles from coast) emissions by ship type (tons/year).

Ship Type	HC	CO	NO_x	PM	SO₂
Bulk Carrier	204	415	8,909	684	5,083
Container Ship	202	407	8,648	762	5,577
General Cargo	70	130	2,850	235	1,742
Miscellaneous	11	18	410	38	283
Passenger	46	88	1,771	266	2,048
Reefer	14	29	626	47	349
Roro	32	63	1,343	122	916
Tanker	142	300	6,116	697	5,329
Vehicle Carrier	18	34	749	58	430
Total	739	1,484	31,423	2,909	21,894

Table 3-4. Reduce Speed Zone (RSZ) emissions by ship type (tons/year).

Ship Type	HC	CO	NO_x	PM	SO₂
Bulk Carrier	553	1,026	15,424	1,223	9,276
Container Ship	942	1,644	16,996	1,513	11,945
General Cargo	185	334	5,386	442	3,249
Miscellaneous	51	86	773	68	527
Passenger	124	211	2,020	208	1,656
Reefer	97	164	1,405	123	991
Roro	48	93	1,468	145	1,116
Tanker	477	891	13,251	1,325	9,847
Vehicle Carrier	109	187	1,984	168	1,327
Total	2,587	4,635	58,707	5,215	39,936

Table 3-5. Maneuvering emissions by ship type (tons/year).

Ship Type	HC	CO	NO_x	PM	SO₂
Bulk Carrier	362	994	1,931	218	1,238
Container Ship	703	1,894	2,204	294	1,462
General Cargo	95	259	451	54	301
Miscellaneous	43	120	128	18	90
Passenger	97	236	362	54	315
Reefer	81	220	233	33	155
Roro	29	78	168	20	119
Tanker	275	728	1,404	183	1,116
Vehicle Carrier	80	218	241	33	161
Total	1,762	4,726	7,120	895	4,912

Table 3-6. Hotelling emissions by ship type (tons/year).

Ship Type	HC	CO	NO_x	PM	SO₂
Bulk Carrier	343	3,472	18,932	543	3,181
Container Ship	512	1,853	10,557	556	4,755
General Cargo	128	1,336	7,391	265	1,639
Miscellaneous	73	842	4,603	121	650
Passenger	77	344	1,991	220	1,774
Reefer	66	342	1,895	60	458
Roro	31	334	1,851	134	964
Tanker	281	2,031	11,247	842	6,180
Vehicle Carrier	52	130	753	32	325
Total	1,563	10,685	59,219	2,774	19,925

The emissions estimates were generated by determining the ratio of vessel activity for each port within the US by the vessel activity within one of several consolidated ports detailed by Arcadis (1999a and 1999b). Each port was matched according to criteria described in Chapter 2. A ratio between each port and the detailed port in terms of load and time in mode for the RSZ mode was also determined from information gathered on the speed and distance of the RSZ for each port. These ratios of port call activity and the RSZ load and time in mode were applied to the emission estimates of the detailed ports to calculate emissions by ship and mode type. The use of the ratio of vessel calls implies that the average vessel size by ship type at each port were identical to those of its matched consolidated ports.

Special information was available for the Houston area (Starcrest, 2000) and California (ARB, 2001) ports. The Houston area data may have been underestimated because the cruise mode did not appear to have been included in the emission estimates. The emission estimates in Houston were adjusted to reflect the emission factors estimated in this work. The California estimates were provided directly from ARB staff and were not adjusted for time, load, or emission factors. California data included transit emissions from the time a ship leaves a harbor till it enters the outer continental shelf area, while the Arcadis results included cruise time out to 25 miles into

the open ocean. The California estimates were not adjusted for the emission factors estimates in Task 1 because the emission factors used by ARB were unknown. Documentation for the California estimates was not available, however the emissions provided were consistent with those provided to SCAQMD (Arcadis, 1999) for the San Pedro Bay ports.

This emission summary does not include emissions generated by ships within US waters that do not call on US ports or those emissions generated in transit to US ports but not within the cruise zone defined by Arcadis (1999). These estimates therefore do not include some transit emissions off the ocean coasts and within the Great Lakes that could affect air quality within the US.

DETAILED PORTS ESTIMATES

In order to estimate the emissions at all ports, it was first necessary to estimate emissions at ports where detailed information about vessel activity and characteristics were available. The emission estimates for the detailed ports provided the basis for estimating emissions at all ports.

Arcadis (1999a and 1999b) provided estimates of the ocean-going vessel activity for several deep sea and Great Lakes ports. The activity estimates that were provided included vessel trips, vessel power, vessel cruise speed, vessel speed in mode, and time in mode where modes were defined as cruise, reduce speed zone (RSZ), maneuvering, and hotelling. The vessel calls were distinguished by vessel (e.g. container, tanker, general cargo, etc.) and propulsion engine type, either 2-stroke slow speed, 4-stroke medium speed, or steamship. The Arcadis reports provided all the required information to estimate emissions except the load and emission factors.

The emissions were calculated by associating and summing the product of the vessel trips or calls, vessel power, average load factor by mode of operation and time in mode for all modes of operation. The equation used for calculating emissions from vessels is shown below. The vessel and engine types were kept as distinct as possible to allow subtotals by vessel, mode, and engine type for each port.

$$\text{Emissions} = \text{Trips} * \text{Power} * \text{LF in mode} * \text{Time in mode} * \text{EF}$$

Trips - number of trips or vessel calls by vessel and engine type

Power - rated power of propulsion engine by vessel and engine type

LF - load factor (fraction of rated power) by mode

Time - average time for each mode by vessel and engine type per call or trip

EF - emission factor in mode and by engine type

The vessel power was assumed to have a load factor of 10% for hotelling and 80% at cruise, following the estimates provided in BAH (1991), which are official EPA guidance at this point. Data from Environment Canada indicated that the cruise mode averaged 84% load for their study. Also, Starcrest (2000) indicated that the hotelling load may be as low as 6% of the engine power. However, these reports indicate that the BAH (1991) values are reasonable average estimates.

For maneuvering and reduced speed zone modes, it was necessary to estimate the load at intermediate levels. In order to estimate the load at vessel speeds other than cruise, a cubic relationship was used and is shown in the equation below. This equation assumes that an auxiliary load of 10% is demanded at a minimum even when the vessel speed is zero. However, there is a question over whether the 10% load for auxiliary equipment is provided by the propulsion engine through a power take-off or from onboard generators. The actual speed of the vessels at each port was estimated from discussions with harbor pilots, while the cruise speed was provided by Arcadis (1999a and 1999b) by vessel type. The equation below demonstrates how the engine load was calculated for intermediate speeds.

$$\text{Load Factor} = 0.1 + 0.7 * (\text{Actual Speed} / \text{Cruise Speed})^3$$

The maneuvering speed was estimated as 4 knots for all ports while the average RSZ speed varied for ports with an average used for the initial calculations shown in Table 3-7 for the detailed ports. The RSZ speed determined the load during this mode through the equation above using the cruise (also called service) speed of the individual vessel types also shown in Table 3-7.

Table 3-7. Average speed during RSZ and Cruise modes for detailed ports.

Port	Indicator	RSZ Speed (knots)	Cruise Speed by Ship Type (knots)									
			BC	CS	GC	OT	PA	RF	RO	TA	VC	
Lower Mississippi area	LM	10	15	20	15	14	21	19	17	15	15	
New York area	NY	10	15	21	16	14	21	22	18	15	18	
Delaware area	DE	10	15	19	14	14	22	19	16	15	18	
Puget Sound area	PS	13	14	21	16	14	19	16	23	16	18	
Corpus Christi	CC	10	15	24	16	13	-	-	-	15	-	
Tampa	TA	9	15	22	14	13	20	18	14	15	18	
Baltimore	BA	14	15	20	15	15	21	19	18	15	18	
Coos Bay	CB	7	14	-	15	15	-	-	-	-	-	
Cleveland *	CL	9	14 (13)	15	14	-	-	-	-	14	-	
Burns Harbor *	BH	9	14 (14)	-	13	-	-	-	-	14	-	

* Vessels are labeled (Laker) or "Salty" referring to transit within the Great Lakes or out to sea.

The motor ship hotelling loads were assumed to be supplied by smaller auxiliary engines themselves operating at higher relative loads but at only 10% of the installed power (installed power was provided by Lloyds and averaged by Arcadis for the detailed ports) on the vessel.

The emission factors for the calculations, taken from Chapter 1 in Table 1-12 for slow speed propulsion, Table 1-13 for medium speed propulsion, Table 1-14 for medium speed auxiliary, and Table 1-15 for steamship power found in the emission factors chapter are summarized in Tables 3-8 and 3-9. There remains a question about whether the emission factors are constant over the entire range of engine loads, however as demonstrated in EPA (2000) the emission factors (in g/hp-hr units) only increase for loads below about 10%.

Table 3-8. Emission factors (g/hp-hr) for transit modes.

Engine Type	HC	CO	NO_x	PM*	SO₂
Slow Speed	0.395	0.82	17.60	1.29	9.56
Medium Speed	0.395	0.52	12.38	1.31	9.69
Steam Boiler	0.05	0.22	2.09	1.86	15.0

*Using an average fuel sulfur level of 3%.

Table 3-9. Emission factors (g/hp-hr) for hotelling modes (Category 2 medium speed engines except steam boilers).

Propulsion Engine Type	HC	CO	NO_x	PM*	SO₂
Slow Speed	0.1	1.85	9.96	0.239	1.07
Medium Speed	0.1	1.85	9.96	0.239	1.07
Steam Boiler	0.05	0.22	2.09	1.86	15.0

* Using an average fuel sulfur level of 0.33% for engines and 3% sulfur for steam boilers.

The assumptions for fuel use in the emission rates shown above are that propulsion engines and steamships use high sulfur (3% by weight) fuel (an approximate average among a summary of bunker fuels found at <http://www.marinelink.com/members/stats/>), but lower sulfur (0.33%) fuel was assumed to be used at dock with auxiliary engines derived from the average nonroad diesel fuel sulfur level found in EPA (1998). However, steamships were assumed to have used high sulfur fuel while at dock though auxiliary diesel generators may supply the electric loads with the steamship boilers shut down.

There is confusion among several knowledgeable parties over the type of fuel used near ports. Some harbor pilots (Starcrest, 2000) have indicated that vessels use low sulfur diesel fuel at some point starting either during the Reduced Speed Zone or Maneuvering modes when the harbor pilots are in command. Once at dock, most vessels use smaller onboard generators running on low sulfur diesel fuel (Starcrest, 2000), so Category 2 medium-speed 4-stroke emission factors using low sulfur fuel were used for hotelling emissions on each vessel. Important for some ports was the estimate, based on information from TRC (1989), that steamship tankers burn heavy fuel oil during hotelling operations. On the other hand, Greg Rideout (2001) indicated that, during his work in the Puget Sound and Vancouver areas (Environment Canada, 1997), there was no evidence that lower sulfur fuels were used near ports in engines for either propulsion or electrical generation, and that on-board diesel generators appeared to run during transit as well as during hotelling modes. One Florida pilot (PCPA, 2001) estimated that only about 5-10% of ships are

equipped with separate tanks to be able to switch to other fuels (either lighter weight and/or lower sulfur fuels) during transit modes.

The emissions results for each of the 10 detailed ports are shown in Appendix A by vessel and propulsion engine type and by mode of operation and for total emissions for all modes. The hotelling emissions for slow speed 2-stroke and medium speed 4-stroke propulsion engines are expected to be generated from Category 2 medium speed engines. Summary estimates are shown below in Table 3-10.

Table 3-10. Summary emission estimates for the detailed ports (tons/year).

Consolidated Detailed Port	HC	CO	NO_x	PM	SO₂
Lower Mississippi	437	2,560	23,204	1,337	9,243
New York	189	937	8,745	685	4,953
Delaware River (Philadelphia et al.)	124	674	6,284	403	2,837
Puget Sound	231	986	11,174	1,135	8,511
Corpus Christi	44	191	1,862	209	1,573
Tampa	41	241	2,055	140	987
Baltimore	160	586	7,444	530	3,844
Coos Bay	5	36	287	14	89
Cleveland	9	36	243	16	111
Burns Harbor	2	10	82	5	36

Relative emissions by mode differed between ports due to the geographic and operational differences between ports and by vessel type. The geographic differences were mainly observed in terms of the length of the RSZ and, to a lesser extent, the cruise mode lengths. At some ports, such as the Lower Mississippi and Puget Sound area ports, the RSZ's begin much further out from port in both distance and time than, for example, New York, Tampa, or Corpus Christi. Hotelling times were important and depended in large part on the prevalent type of vessel call, where, for instance, bulk carriers tend to spend longer in port than container ships.

Hotelling modes tended to be the largest source of NO_x emissions for a port because of the length of this operational mode in comparison with the transit modes. The transit modes for cruise and RSZ tended to be of greater importance for PM emissions because of the high sulfur fuel assumed to be used during transit. Maneuvering modes tended to be less important because the length of this mode was short and the engine load was low.

Some vessels in 1996 (the year for which the Arcadis, 1999a and 1999b data were valid) were still propelled by steamship boilers and turbines, with the relative number of steamships varied from port to port. The steamships are likely to be mostly replaced by Category 3 motorships because of the greater efficiency of these engines. The steamship NO_x emission rates are significantly lower than those from motorships, so the NO_x emissions will be higher in the future even without growth in activity of large merchant vessels. The fraction of vessels with steamship propulsion in 1996 for the detailed ports is summarized in Table 3-11. The transit emissions

included emissions from steamships which do not fall under the description of Category 3 engines, but the steamship vessel activity will be mostly served by vessels with Category 3 engines in the future.

Table 3-11. Fraction of steamship calls at different ports in 1996.

Port	Steamship Fraction of Tankers	Steamship Fraction of Total
Lower Mississippi	1.2%	3.2%
New York	10.1%	11.1%
Delaware River (Philadelphia and others)	10.4%	4.0%
Puget Sound	59.9%	20.3%
Corpus Christi	40.3%	34.5%
Tampa	32.9%	10.7%
Baltimore	5.4%	3.8%
Coos Bay	0.0%	0.0%
Cleveland	0.0%	6.2%
Burns Harbor	0.0%	4.8%

METHODOLOGY FOR MATCHED PORTS

These ports were matched to the detailed vessel characteristics for the ports described above as described in the Chapter 2 report using the procedure described by Arcadis (1999). The Arcadis report detailed a 12 step process (outlined below) for determining activity estimates for the matched (or Modeled) ports. In this work, the terminology "detailed" or "typical" ports refers to the ports where detailed vessel characteristics and activity were summarized in the Arcadis (1999) report. The term "matched" or "modeled" port refers to the ports where detailed activity and vessel characteristics were not available.

- Step 1. Determine a Modeled Port and a Typical Port
- Step 2. List USACE Port Codes Within the MEPA Area
- Step 3. Total All Trips for the Ports in Step 2
- Step 4. Determine Trips for the Typical Port
- Step 5. Determining the Number of Calls for the Typical Port
- Step 6. Determine the Distance to the Port/Waterway
- Step 7. Determine the Distance from the Breakwater to the Typical Port
- Step 8. Compute RSZ for the Typical Port
- Step 9. Determine Trips for the Modeled Port
- Step 10. Compute the Number of Calls for the Modeled Port
- Step 11. Compute the revised reduced speed zone
- Step 12. Allocation to Counties

For this work the steps described were generally followed with exceptions noted here below. In order to produce national estimates for all Category 3 vessels, a more straight-forward methodology was used compared to the Arcadis methodology.

Step 1 was provided in the Chapter 2 report. In our work, the 10 detailed ports provided by Arcadis (1999) will be used for the detailed (or also called typical) port designation, rather than using specific ports within the detailed port information as Arcadis (1999) described in their example using Bellingham (one of many Puget Sound ports) as the typical port.

Step 2 was simplified by using the entire detailed port vessel characteristics (e.g. all of the ports within the Puget Sound Marine Exchange and Port Authorities (MEPA)) rather than just Bellingham as given in the example described by Arcadis (1999)) as the basis for matched port vessels. In some cases, the detailed ports data set provided by Arcadis (1999) included vessel information from all ports within the MEPA area. Instead of extracting individual port information from the detailed data set, this work used the MEPA data in its entirety for port matching. Also, the ports within each MEPA area (Table 1-1 in Arcadis, 1999) were excluded from the matched port list as the activity at all ports was assumed to be included in the totals for the detailed ports.

Steps 3 and 4 were followed for this work. The summary data for the detailed ports and the individual matched ports used the Arcadis-supplied United States Army Corps of Engineers (USACE) trip data for 1995 to determine relative activity by vessel type. Based on a review of several operators (e.g. Seabulk International, Crowley, and Foss), many types of vessels were not considered to have Category 3 engines onboard, including barge carriers (BA), dry cargo barges (BD), liquid barges (BL), supply vessels (SV) such as used for off-shore oil and gas production, and tugs (TUG) or fishing vessels. There were also unclassified vessels, which were mapped into the dry cargo vessels as described by Arcadis (1999). Matched ports may have trips recorded for vessel types that were not found in the detailed port data, so these vessel types were mapped into the OTHER or MISCELLANEOUS category characteristics for these vessels. This is demonstrated in Appendix B for the Texas ports.

Step 5 was handled much as described by Arcadis except that the total estimate for detailed ports (combination of the MEPA ports) was used instead of individual ports.

Steps 6 through 8 and Step 11 were handled differently and more directly than the described approach by contacting individual ports for information about average vessel speed and distance within each reduce speed zone (RSZ). This was done for each matched port except for Great Lakes ports, which were assumed to be similar for all modes of operation.

Steps 9 and 10 formed the basis for determining the large ocean-going vessels (OGV) counts at the matched ports using the Arcadis (1999) 1995 vessel trips data. An attempt was made to revise the trip data using USACE (2001) information for 1996 and 1999, but encountered difficulties in determining reasonable trip counts between certain ports. The trip data included vessel trips by 6 general types: Self-Propelled Dry Cargo, Self-Propelled Tanker, Towboat, Non-Self Propelled Dry Cargo, Non-Self Propelled Tanker, Other (undefined). Arcadis reported to have used a ratio

of the 6 general types to map into the more detailed classifications. However, this procedure led to some unreasonable estimates of total trips for some ports, such as Seattle-Tacoma where self-propelled dry cargo trips increased by 10 to 20 times between 1995 and 1996. This increase in trips would have translated to an unreasonable increase from 1995 to 1996 for most vessel trips. Additional work would be needed to determine which method is most correct for determining vessel trips.

Step 12 was omitted in this work because county level emissions estimates were not requested.

In summary, the method used determined a ratio of the matched port to the detailed port summaries in terms of vessel calls by ship type to calculate emissions directly for cruise, maneuvering, and hotelling activity. The reduce speed zone (RSZ) load and time in mode was calculated specifically for each port based on the geography and discussions with harbor pilots or other officials. For other modes, each vessel call at the matched port is considered to be equivalent to that of the detailed port. The summary emission and RSZ speed and distance estimates by port are shown in Table 3-12 and were combined with the estimates for the detailed ports in Table 3-10 to provide national totals. The Houston-Galveston and California ports estimates were provided by the TNRCC and ARB and were not calculated in this work.

Table 3-12. Emission estimates and reduced speed zone parameters by port.

Port	Matched Port*	Emissions (tons/year)					RSZ (knots and miles)	
		HC	CO	NOx	PM	SO ₂	Speed	Distance
Brownsville, TX	TA	12	85	644	34	227	8.8	18.5
Gulfport Harbor, MS	TA	5	49	322	13	81	10.0	17.0
Matagorda Ship Channel, TX	TA	6	34	284	20	143	7.3	24.0
Orange, TX	TA	1	2	25	2	11	7.0	53.5
Panama City Harbor, FL	TA	6	41	332	18	119	10.0	10.0
Pascagoula Harbor, MS	TA	19	111	937	66	465	10.0	17.0
Pensacola Harbor, FL	TA	2	17	129	7	45	12.0	12.0
Port Arthur, TX	TA	20	114	978	86	628	7.0	20.0
Beaumont, TX	CC	18	72	757	89	675	7.0	56.5
Lake Charles, LA	CC	23	110	1,007	103	767	6.0	24.0
Mobile Harbor, AL	CC	29	130	1,263	91	656	11.0	35.0
Port Everglades Harbor, FL	LM	138	1,304	8,601	465	3,086	7.5	2.0
Houston-Galveston Area Ports	-	209	867	8,810	573	3,437	6 to 12	5 to 40
						estimated		
Jacksonville Harbor, FL	DE	41	255	2,122	118	802	10.0	15.0
Port of Boston, MA	DE	20	132	1,054	67	466	10.0	15.0
Charleston Harbor, SC	DE	38	222	1,899	111	764	12.0	17.0
New Haven Harbor, CT	DE	8	69	486	25	167	10.0	2.0
Port of Wilmington, NC	DE	26	156	1,318	77	529	10.0	28.0
Providence, RI	DE	8	58	445	26	179	9.0	22.0
Morehead City Harbor, NC	DE	6	43	346	19	132	10.0	28.0
Bridgeport Harbor, CT	DE	1	11	77	4	23	10.0	2.0
Fall River Harbor, MA	DE	3	24	185	9	59	9.0	22.0
Palm Beach Harbor, FL	DE	22	172	1,261	62	402	3.0	3.0
Canaveral Harbor, FL	DE	14	103	759	51	354	10.0	4.0
Portsmouth Harbor, NH	DE	2	17	121	7	48	10.0	2.0
Port Jefferson Harbor, NY	DE	0	0	2	0	1	10.0	2.0
Brunswick Harbor, GA	DE	11	58	545	31	215	13.0	45.5
Searsport Harbor, ME	DE	3	19	146	8	55	9.0	22.0
Bucksport Harbor, ME	DE	1	5	38	2	17	9.0	22.0

Port	Matched Port*	Emissions (tons/year)					RSZ (knots and miles)	
		HC	CO	NOx	PM	SO _x	Speed	Distance
Georgetown Harbor, SC	DE	3	26	199	9	61	12.0	17.0
Port of Richmond, VA	DE	27	132	1,311	79	550	10.0	100.0
Port of Hopewell, VA	DE	3	15	139	8	55	10.0	82.0
Miami Harbor, FL	DE	143	893	7,193	537	3,818	12.0	3.0
Newport News, VA	BA	25	154	1,328	83	579	14.0	22.0
Savannah, GA	BA	87	445	4,370	283	2,001	13.0	45.5
Norfolk Harbor, VA	BA	40	213	1,984	137	970	14.0	24.0
Portland, ME	NY	9	56	426	28	194	10.0	11.0
Portland, OR	PS	67	313	3,274	306	2,273	12.0	93.0
Vancouver, WA	PS	23	121	1,190	77	547	12.0	94.0
Kalama, WA	PS	13	80	720	43	303	12.0	69.0
Longview, WA	PS	19	120	1,054	61	420	12.0	59.0
Honolulu, HI	PS	25	175	1,374	123	900	4.0	7.0
Barbers Point, HI	PS	4	24	187	41	316	4.0	7.0
Valdez, AK	PS	19	94	812	228	1,798	10.0	27.0
Ketchikan, AK	PS	14	117	795	59	412	14.0	14.0
Port of Astoria, OR	PS	9	73	531	25	161	12.0	14.0
Kahului, Maui, HI	CB	1	5	43	2	13	4.0	7.0
Hilo, HI	CB	0	1	9	0	3	4.0	7.0
Nawiliwili, Kauai, HI	CB	0	3	20	1	6	4.0	7.0
Nikiski, AK	CB	0	1	15	1	6	14.5	84.0
Anchorage, AK	CB	1	5	64	4	30	14.5	144.0
ALL California ports	-	4,084	7,479	29,900	2,793	23,186	-	-
Duluth-Superior, MN & WI	CL	15	67	449	28	191	-	-
Indiana Harbor, IN	CL	5	20	139	10	68	-	-
Port of Detroit, MI	CL	6	24	168	12	79	-	-
Lorain Harbor, OH	CL	6	26	176	12	80	-	-
Toledo Harbor, OH	CL	7	31	209	13	90	-	-
Presque Isle Harbor, MI	CL	3	14	95	6	44	-	-
Ashtabula Harbor, OH	CL	4	17	114	8	53	-	-
Gary Harbor, IN	CL	2	8	54	4	26	-	-
Taconite Harbor, MN	CL	2	8	52	4	24	-	-
Escanaba, MI	CL	3	12	80	5	37	-	-
Two Harbors, MN	CL	2	7	48	3	23	-	-
St. Clair, MI	CL	2	11	75	5	31	-	-
Conneaut Harbor, OH	CL	2	12	78	5	31	-	-
Silver Bay, MN	CL	2	7	47	3	22	-	-
Marine City, MI	CL	1	4	25	2	12	-	-
Sandusky Harbor, OH	CL	4	18	121	8	52	-	-
Ludington Harbor, MI	CL	1	2	16	1	8	-	-
Port of Chicago, IL	BH	4	18	146	9	65	-	-
Stoneport, MI	BH	3	16	136	9	60	-	-
Calcite, MI	BH	3	17	138	9	61	-	-
Port Inland, MI	BH	2	10	87	6	38	-	-
Marblehead, OH	BH	2	8	69	4	31	-	-
Milwaukee Harbor, WI	BH	2	9	75	5	33	-	-
Port Dolomite, MI	BH	1	7	58	4	26	-	-
Fairport Harbor, OH	BH	3	19	136	7	46	-	-
Alpena Harbor, MI	BH	2	11	95	6	42	-	-
Green Bay Harbor, WI	BH	1	5	38	2	17	-	-
Monroe Harbor, MI	BH	1	3	23	1	10	-	-
Port of Buffalo, NY	BH	1	5	37	2	14	-	-
Muskegon Harbor, MI	BH	1	4	33	2	15	-	-
Drummond Island, MI	BH	1	3	27	2	12	-	-
Charlevoix Harbor, MI	BH	1	3	28	2	12	-	-
Buffington Harbor, IN	BH	0	2	16	1	7	-	-

Port	Matched Port*	Emissions (tons/year)					RSZ (knots and miles)	
		HC	CO	NOx	PM	SO _x	Speed	Distance
Huron Harbor, OH	BH	1	3	21	1	9	-	-
Erie Harbor, PA	BH	3	19	134	7	43	-	-
Grand Haven Harbor, MI	BH	1	3	25	2	11	-	-

* Legend for the matched ports is given in Table 3-7

4. BETWEEN PORT EMISSIONS

INTRODUCTION

The method to determine between port emissions was described by Corbett and Fischbeck (2000) for emissions in the open ocean and Great Lakes by associating activity estimates from the USACE (2002) in terms of ton-miles of freight activity with emission rates in terms of ton-miles. Other methods were considered, such as tracking the domestic fleet through next and last port of call information from the Marine Exchange or Port Authority (MEPA), but were deemed unreliable for determining the routes of passage of vessels powered by Category 3 engines. Often next and last ports of call were unknown or indicated that foreign vessels were traveling between two US ports, which is illegal according to US cabotage law. The estimates using the USACE (2002) activity estimates appear to significantly underestimate emissions between ports however.

River traffic other than those vessels used in the open ocean were considered to be powered by Category 2 or smaller engines based on a review of many operators' fleets. Tow boats hauling freight by barge were considered to not operate outside of 25 nautical miles from ocean and 10 miles from Great Lakes shores.

Passenger vessels were not explicitly characterized by this approach such as cruise ships because freight tonnage was not a representative indicator of activity. The cruise vessel emissions were incorporated through the emission factor estimates by summing cruise vessel emissions along with the freight vessel emissions divided by the associated freight tonnage at each port.

TOW AND PUSH BOAT TRAFFIC

In previous work (Corbett and Fischbeck, 1998), Category 3 engines were projected to produce emissions along river ways and near coasts. This section addresses whether Category 3 engines are used to provide power by tugs for much of the traffic along these inland waterways and near ocean coasts. Tugs (a term used here to indicate both tow and push boats) handle much (mostly domestic) freight traffic on ocean and river links. A search of the many operators (described below) indicated that most tugs are powered by engines not considered Category 3. Corbett and Fischbeck (1998) found rare instances where tugs were powered by Category 3 engines though these were few.

Except for river ports serving ocean-going traffic, all river traffic was assumed to be handled by push boats or other craft propelled by Category 1 or 2 engines. From BTS (1999) quoted below, it is clear that almost all of the river freight is handled by barges pushed by tugs.

“In 1997, barges transported 96 percent of the tonnage that moved on inland waterways.”

A review of the fleets of several tug operators showed that such tugs overwhelmingly use smaller displacement engines than Category 3. Large ocean-going tugs (up to 10,000 hp) and river

pushboats (up to 8,000 hp) use US manufactured engines, all Category 2 or smaller engine types. Below are shown a variety of tugs and push boats operating in the U.S., and none of those shown use Category 3 engines.

Crosby Tugs; Golden Meadow, LA

<http://www.crosbytugs.com/fleet.htm>

Examples of largest tugs

M/V Crosby Duke - (2) Caterpillar 3516 DITA SCAC "B HD; 9,000 hp; #570147

M/V Crosby Star - (2) 3516 Caterpillar w/ 6:1 Reduction (Kort Nozzles); 6,000 hp; #1060046

Crowley Marine Services, Inc.; Seattle, WA

http://www.crowley.com/cms/vessel_specs_one.asp

Examples of largest tugs

Nanuq - 2 Caterpillar 3612-B; 10,192 hp; #1074361

Garvey Marine, Inc.; St. Charles, IL

<http://www.garveyintl.com/marine/lemont.htm>

Examples of largest tugs

Julie White, 1,900 hp (no Category 3 engines at this power level)

Hannah Marine Corporation; Lemont, IL

<http://www.hannahmarine.com/equipment.htm>

Examples of largest tugs

M/V SUSAN W. HANNAH; Two (2) EMD 12-645 E5; 4,350 hp; #582617

McDonough Marine Service; New Orleans, LA

<http://www.mcdonoughmarine.com/>

Examples of largest tugs

M/V CLAUDE R; (2) Detroit Diesel 8V-149 DDEC; 1,600 hp;

Riverway Company; Minneapolis, MN

<http://www.riverway.com/bootsieb.htm>

Examples of largest tugs

M/V BOOTSIE B; EMD 16 cylinder 710G7B; 8,000 hp;

Seabulk International

<http://www.seabulkinternational.com/>

Examples of largest tugs

Seabulk Montana; Alco 12-251; 5,600 hp

Seabulk Nevada; (2) EMD 16-645-E5; 5,750 hp

Seabulk New Jersey; (2) Caterpillar 3606; 4,800 hp

For this work then, large ocean-going merchant vessels were considered the only vessel type that

use Category 3 engines. Category 3 engine emissions on rivers were considered to be derived only from ocean-going vessels accessing river ports (such as Portland (OR), Vancouver (WA), Baton Rouge, New Orleans, Albany (NY)) and were included in the emission estimates for those ports serving ocean-going traffic. The emissions along the rivers were included in the reduced speed zone and maneuvering operating modes for these ports. Other river traffic, such as push boats and barges, was considered to be propelled by Category 1 and 2 engines.

ACTIVITY ESTIMATES

In order to determine the activity of vessels powered by Category 3 engines operating to and from and between US ports, it was first determined that river traffic was handled by tugs powered by Category 1 or 2 engines as indicated above. River activity was therefore ignored except to the extent that large merchant ships, either ocean-going or Great Lakes, are involved in transport.

The method used by Corbett and Fischbeck (2000) was recreated in this report. For ocean and Great Lakes traffic, USACE (2002) provided activity estimates of total and domestic tonnage by waterway links. These estimates were converted to ton-miles estimates by multiplying tonnage by link distance to estimate overall activity. In order to make these estimates correspond to the previous method (Corbett and Fischbeck, 2000) and not double count the emissions estimated in Chapter 3, a criteria was used to determine the links and fractional links appropriate for estimating emissions. For ocean links, only links between 200 statute and 25 nautical miles from shore were used to determine emissions. For Great Lakes links, links outside of 10 nautical miles (7 miles of cruise and 3 miles of reduced speed activity) from shore were used to estimate emissions. Traffic within 25 nautical miles from the coast were considered to have been estimated in the by-port estimates in effect assuming that no transit emissions occur with 25 nautical miles from the coast other than vessels directly heading to and from ports.

The activity estimates were intended to be distinct from the port traffic by only applying the activity outside of 25 nautical miles from shore, however vessel activity may occur within the 25 mile limit but not within 25 miles from next or last port of call. Appendix C includes maps of all vessel links and maps of links within the 25 to 200 mile limits. Many coastal links are excluded because it was not possible to exclude, from the USACE (2002) data, barge traffic or near port activity captured under the estimates provided in Chapter 3. For reference, a comparison of the domestic ocean trip traffic from BTS (1999) and this work is provided in Appendix D indicating that the activity estimates in this work are potentially low.

Future year relative tonnage emission estimates were determined from the sum of the detailed ports tonnage estimates including the relative growth rates for container ship, tanker, and all other freight traffic as described in Chapter 5.

Table 4-1. Tonnage activity relative to 1996 base year.

Link type	2010	2020	2030
Ocean	1.52	2.05	2.82
Great Lakes	1.43	1.91	2.56

EMISSION FACTORS

The emission factors were determined from the calculation of emissions for the cruise mode at each of the detailed ports described in Chapter 3. Cruise mode emissions were divided by the freight tonnage reported for these ports and 50 nautical miles assuming that each port call results in 50 miles of cruise (25 miles in and 25 miles out) for ocean traffic and 14 miles of cruise for Great Lakes traffic according to activity estimated by Arcadis (1999a and 1999b).

Table 4-2. 1996 emission factors (g/ton-nautical-mile) for Category 3 propulsion engines.

	HC	CO	NO_x	PM	SO₂
Baltimore MEPA	0.0162	0.0330	0.7075	0.0564	0.4200
Philadelphia MEPA	0.0078	0.0155	0.3319	0.0275	0.2052
New York MEPA	0.0213	0.0434	0.9172	0.0836	0.6291
New Orleans MEPA	0.0090	0.0183	0.3924	0.0308	0.2294
Corpus Christi	0.0055	0.0118	0.2368	0.0292	0.2244
Tampa	0.0103	0.0198	0.4258	0.0389	0.2913
Puget Sound MEPA	0.0157	0.0337	0.6902	0.0737	0.5618
Coos Bay	0.0121	0.0251	0.5389	0.0396	0.2935
Avg. Ocean	0.0122	0.0251	0.5301	0.0475	0.3568
Corbett and Fischbeck (2000)* Ocean	0.0105	0.0323	0.3625	0.0295	-
Cleveland	0.0085	0.0164	0.3535	0.0309	0.2311
Burns Harbor	0.0058	0.0115	0.2486	0.0196	0.1459
Avg. Lakes	0.0071	0.0140	0.3101	0.0253	0.1885
Corbett and Fischbeck (2000)* Lakes	0.0087	0.0269	0.3021	0.0246	-

* Diesel engine emissions uncorrected for steamships; and emissions were assumed to have been given by Corbett and Fischbeck (2000) in terms of statute mile and converted here to like units.

The emission estimates per ton-mile in this work compared favorably with those of Corbett and Fischbeck (2000) as shown in Table 4-2. The primary difference in NO_x and PM emission rates were that baseline emission factors in this work were higher (by about 38% for NO_x and about 20% for PM for motorships) than those of Lloyds (1995), which were used by Corbett and Fischbeck (2000). Another difference is that steamship emission were not included by Corbett and Fischbeck (2000) estimates provided above, which would result in higher PM and lower

NOx emissions than those shown for Corbett and Fischbeck (2000).

Corbett and Fischbeck (2000) made a number of assumptions in deriving their estimates including average vessel characteristic and typical freight loading, while the estimates in this work used information on specific vessels and actual freight tonnage calling on the detailed ports. The fact that both estimates, having been derived by completely unique methods, yield emission rate estimates so similar provided confidence that these estimates were comparable.

Future year emission factors were determined using the same method described above but using emission and activity estimates from Chapter 5. These future year average estimates are shown in the Table 4-3. The change in emission factors from year to year is a combination of many factors including growth rates in traffic served by increasing vessel size, emission controls for NOx emissions, fraction of passenger ship activity, and lower fraction of steamship calls.

Table 4-3. Future year emission factors (g/ton-nautical-mile) for Category 3 propulsion engines.

Estimate	HC	CO	NOx	PM	SO2
Avg. Ocean 2010	0.0133	0.0272	0.5047	0.0482	0.3605
Avg. Ocean 2020	0.0145	0.0295	0.4931	0.0508	0.3785
Avg. Ocean 2030	0.0160	0.0323	0.5124	0.0546	0.4062
Avg. Lakes 2010	0.0070	0.0139	0.2607	0.0242	0.1802
Avg. Lakes 2020	0.0068	0.0136	0.2293	0.0232	0.1727
Avg. Lakes 2030	0.0067	0.0134	0.2132	0.0225	0.1672

RESULTS

The emission factors were associated with the ton-miles estimates in the 25 nautical mile and 200 statute mile region. These emission estimates are shown in the Tables 4-4 through 4-7 for all and domestic-only traffic. The ‘domestic’ traffic label by USACE may have included freight US exports as well as between US port traffic, so it may have been carried by foreign flagged vessels.

Table 4-4. Transit emissions (tons per year) for **all** freight vessel traffic on ocean links.

Estimate	HC	CO	NO_x	PM	SO₂
Ocean 1996	1,580	3,251	68,705	6,152	46,248
Ocean 2010	2,618	5,354	99,428	9,488	71,026
Ocean 2020	3,850	7,832	131,015	13,487	100,575
Ocean 2030	5,844	11,797	187,279	19,941	148,477

Table 4-5. Transit emissions (tons per year) for **domestic** freight vessel traffic on ocean links.

Estimate	HC	CO	NO_x	PM	SO₂
Ocean 1996	1,307	2,688	56,816	5,087	38,245
Ocean 2010	2,165	4,428	82,223	7,847	58,735
Ocean 2020	3,184	6,477	108,343	11,153	83,171
Ocean 2030	4,832	9,755	154,872	16,490	122,784

Table 4-6. Transit emissions (tons per year) for **all** freight vessel traffic on Great Lakes links.

Estimate	HC	CO	NO_x	PM	SO₂
Lakes 1996	480	935	20,132	1,688	12,608
Lakes 2010	677	1,327	24,203	2,309	17,235
Lakes 2020	879	1,735	28,433	2,956	22,062
Lakes 2030	1,161	2,291	35,434	3,843	28,629

Table 4-7. Transit emissions (tons per year) for **domestic** freight vessel traffic on Great Lakes links.

Estimate	HC	CO	NO_x	PM	SO₂
Lakes 1996	320	623	13,415	1,125	8,401
Lakes 2010	451	884	16,127	1,538	11,484
Lakes 2020	586	1,156	18,946	1,970	14,701
Lakes 2030	773	1,526	23,610	2,561	19,076

Using this method, the total emissions for all vessels (sum of Table 4-4 and 4-6) in this zone, 25 nautical to 200 statute miles, is considerably lower than one would estimate extending the cruise mode in Chapter 3 out to 200 statute miles. For instance in Chapter 3, a total of 31,423 tons per year of NO_x was found in cruise mode, such as 0 to 25 nautical miles from the ocean coasts, compared with 88,837 tons per year of NO_x found here though much more transit occurs within this zone than the comparison indicates.

A comparison of the Corbett and Fischbeck (1998) and the results in this work (Chapter 3 and 4) is provided in Appendix E indicating similar results.

5. FUTURE YEAR PORT EMISSION ESTIMATES

INTRODUCTION

In order to project emission estimates to future years, several factors were taken into account, including the overall activity growth, the type of vessel to be used to handle the demand growth, and the fleet turnover to estimate the effect of the MARPOL regulations. Overall growth trends relied on the freight demand forecasts to estimate the overall activity of vessels. In order to determine the impact on the fleet, an assumption was made that the increased freight traffic would be handled primarily by the largest ships (using slow speed engines), as ports and shipbuilders accommodate increasing ship sizes. The effect of fleet turnover on fleet emission factors was estimated using the MARPOL standards compared with the baseline emission rates distributed over a normal scrappage distribution and applied by vessel propulsion type.

FREIGHT PROJECTIONS

The vessel activity demand was estimated using the freight forecasts described below. MARAD supplied estimates for freight forecasts for 1999 through 2004 for several types of vessels. These estimates were extrapolated using an exponential growth estimate and are comparable to other freight growth estimates through 2020 as shown in Table 5-1. The growth was projected from the 1996 base year for the initial emission estimates, so the historic freight growth from 1996 to 1999 was used and then projected beyond 1999 with the 1999-2004 projection. Growth to 2030 was extrapolated using the same exponential form as for the 2020 calculations with the understanding that such a long projection or extrapolation is uncertain.

Table 5-1. MARAD supplied estimates of US foreign demand growth from McGraw-Hill.

Vessel Type	Annual Growth Rate (1999 - 2004)	Cumulative Growth (1996 - 2020)	Cumulative Growth (1996 - 2030)
Tankers (tonnes)	2.2 %	80 %	124%
Other Bulk and General Cargo (tonnes)	3.0 %	97 %	164%
Container Ships (TEU)	6.2 %	337 %	700%
Cruise (passengers)	6.6 %	381 %	810%

FHWA (2001) provided overall freight projections, but the freight traffic presented by FHWA was dominated by truck traffic, so these projections may not be necessarily applicable to marine freight. This FHWA presentation showed the freight growth from 1998 through 2020 is expected to be 2.9% per year for domestic and 3.4% per year for international trade. Regionally, the freight

growth in the western states is expected to be 3.2% overall and 2.7% in the northeast states, with midwest, gulf, and southeast Atlantic states at 2.9%. These overall freight projections provide justification for the MARAD estimates that were provided above and used for this work.

INCORPORATION OF THE GROWTH IN THE EMISSION CALCULATIONS

In order to incorporate the growth into the emissions calculations, the overall dead weight tonnage (DWT) calling annually at ports was increased in proportion to the projected freight increases. While dead weight tonnage may not directly relate to freight, it was the only measure of size afforded by the 1996 activity data to relate to freight tonnage. The total DWT for the detailed ports was calculated by multiplying vessel calls by average dead weight tonnage for each of several categories of vessels. The additional vessel calls needed to accommodate the growth in activity were added to the largest DWT category of the vessels by type. This was estimated based on assessments by MARAD and BTS (1999) that predominately larger vessels are being built to handle replacement of old vessels and increased freight traffic, and that ports are accommodating larger vessels.

EMISSION RATES INCLUDING FLEET TURNOVER

The proposed MARPOL regulations were developed under aegis of the International Maritime Organization (IMO). These regulations test the engine under three different loads and average the results to compare with an overall emission standard. The emission standard is related to the rated engine speed through the relationship shown below for new vessels constructed after January 1, 2000.

$$\begin{aligned} & \text{Engine Speed} < 130 \text{ rpm}; \quad 17.0 \text{ g/kW-hr} \\ & 130 \text{ rpm} \leq \text{Engine Speed} < 2,000 \text{ rpm}; \quad 45 * n^{-0.2} \text{ g/kW-hr} \\ & \text{Engine Speed} \geq 2,000 \text{ rpm}; \quad 9.8 \text{ g/kW-hr} \end{aligned}$$

where "n" is the engine speed in rpm units

In order to estimate the effect of the NO_x emission standard on average emission rates, it was first necessary to estimate the in-use fleet age distribution. Data was available from BTS (1999) that estimated the average age of the in-use worldwide fleet at 13 years. Using an estimated growth rate and scrappage distribution, a median age at the time of vessel scrappage (or "median lifetime") was calculated to reflect the 13 year-old average age of the in-use fleet. The normal scrappage rate distribution shown in Table 5-2 was taken from the default input to the NONROAD model, which requires an estimate of the median (or average) age when vessels are scrapped. The scrappage rate was applied to the initial (new vessels in each year) relative population (demonstrate by example in Table 5-4 below where new vessels in each year progressively increase) of vessel by model year to determine the remaining fleet age distribution. This remaining fleet age distribution was then used to determine the average age of the in-use

fleet to determine the age at the time of scrappage to produce a 13 year average age of the in-use fleet.

Table 5-2. Normal scrappage distribution.

Normal Distribution	
Relative Age	% Scrapped
0	0
0.06	1
0.12	2
0.17	3
0.22	4
0.24	4.5
0.26	5
0.3	6
0.4	8
0.45	10
0.5	11
0.55	13
0.6	14
0.65	15
0.7	18
0.75	19
0.8	21
0.85	24
0.9	25
0.95	31
1	50
1.05	69
1.1	75
1.15	76
1.2	79
1.25	81
1.3	82
1.35	85
1.4	86
1.45	87
1.5	89
1.55	90
1.6	92
1.7	94
1.72	95
1.74	95.5
1.78	96
1.83	97
1.88	98
1.94	99
2	100

The relative initial vessel population affected the calculated average age of the in-use fleet by skewing the fleet age distribution. So a historic growth rate of the vessel fleet of 2.0% per year

was estimated from data provided by MARAD (2001) from McGraw-Hill and shown in Table 5-3.

Table 5-3. MARAD supplied estimates of historic fleet growth.

Vessel Type	Growth per Year
Tankers	1.2 %
Bulk Carriers	2.1 %
Container Ships	11.8 %

Using an average 2.0% growth rate and the normal scrappage distribution, the median age at the time of scrappage (i.e. the median or average life of vessels) is 25 years in order to have the average age of the in-use fleet be 13 years. Using 0.0% growth, the median age of vessels at the time of scrappage was calculated to be 22 years, so the median age of scrapped vessels is not very sensitive to the estimated fleet growth rate. The 25 year estimate was consistent with the Corbett and Fishbeck (1998) information on the average age of broken up vessels. Shown in Table 5-4 is the age distribution in 2010 calculated with the assumptions detailed above.

Table 5-4. Age distribution of merchant vessels calculated for 2010.

Model Year	Normalized Age	Initial Relative Population	Remaining Population	In-Use Distribution
2010	0.00	132	132	0.0257
2009	0.04	259	259	0.0504
2008	0.08	254	251	0.0489
2007	0.12	249	244	0.0474
2006	0.16	244	239	0.0465
2005	0.20	239	232	0.0451
2004	0.24	234	224	0.0436
2003	0.28	230	218	0.0425
2002	0.32	225	212	0.0412
2001	0.36	221	208	0.0404
2000	0.40	216	199	0.0388
1999	0.44	212	195	0.0380
1998	0.48	208	187	0.0365
1997	0.52	204	182	0.0353
1996	0.56	200	174	0.0339
1995	0.60	196	169	0.0328
1994	0.64	192	165	0.0322
1993	0.68	188	160	0.0312
1992	0.72	185	152	0.0295
1991	0.76	181	147	0.0286
1990	0.80	178	140	0.0273
1989	0.84	174	138	0.0268
1988	0.88	171	130	0.0253
1987	0.92	167	126	0.0244
1986	0.96	164	113	0.0220
1985	1.00	161	80	0.0157

Model Year	Normalized Age	Initial Relative Population	Remaining Population	In-Use Distribution
1984	1.04	158	79	0.0154
1983	1.08	155	48	0.0093
1982	1.12	152	38	0.0074
1981	1.16	149	36	0.0069
1980	1.20	146	31	0.0060
1979	1.24	143	30	0.0058
1978	1.28	140	27	0.0052
1977	1.32	137	25	0.0048
1976	1.36	135	20	0.0039
1975	1.40	132	18	0.0036
1974	1.44	129	18	0.0035
1973	1.48	127	16	0.0032
1972	1.52	124	14	0.0027
1971	1.56	122	12	0.0024
1970	1.60	120	10	0.0019
1969	1.64	117	9	0.0018
1968	1.68	115	9	0.0018
1967	1.72	113	6	0.0011
1966	1.76	110	5	0.0010
1965	1.80	108	4	0.0008
1964	1.84	106	3	0.0006
1963	1.88	104	2	0.0004
1962	1.92	102	2	0.0004
1961	1.96	100	1	0.0002

The results of the emission reductions were determined from the age distribution shown above, projected for future years, and are shown in Table 5-5. For future year emission factor estimates, only a fraction of the vessels in operation would have been built after 2000 resulting in a partial emissions reduction associated with the emission standards beginning in 2000.

Table 5-5. NO_x emission factors (g/hp-hr) and % reduction from baseline emissions with the implementation of the MARPOL standard and in **BOLD** adjusted by increasing future year engine emissions to 10% above the emission standards with the use of residual fuel.

Engine Type	Baseline NO _x	MARPOL NO _x	% Reduction by 2010	% Reduction by 2020	% Reduction by 2030
Slow Speed (~ 130 rpm)	17.6	12.7 13.9	13.1 % 9.8%	22.2 % 16.5%	26.6 % 19.8%
Medium Speed (~ 520 rpm)	12.4	9.6 10.6	10.6 % 6.9%	17.9 % 11.6%	21.6 % 14.0%
Auxiliary (Category 2 (~ 800 rpm))	10.0	8.8	5.4 %	9.2 %	11.0 %

RESULTS

Applying the growth estimate for DWT by adding port calls to the largest category slow speed vessels, an estimate of the overall activity at all ports was determined. By adjusting the NO_x emission factors according to the expected effect from implementing the MARPOL standard, an estimate of the emissions for future years was made, as shown in Table 5-6. Because the States' of Texas and California estimates were used directly and not estimated in this work, the emission estimates for the Houston area and California ports were adjusted according to the average effect of the sensitivity analysis on all other ports.

Table 5-6. Ports emissions summary including activity growth.(tons/year)

Ports	HC	CO	NO _x	PM	SO ₂
1996	6,650	21,529	156,478	11,794	86,763
2010	10,581	33,745	229,307	17,386	125,979
2020	15,325	48,268	312,933	24,243	174,226
2030	23,169	71,958	456,772	35,692	254,950

Because of the large growth rate of container and passenger vessels, the significance of these types of vessels becomes much more important the further in the future that the projections are made. Tables 5-7 through 5-10 compare the 1996 baseline emission estimates with those for 2010, 2020 (the future year where growth projections were provided by reference), and 2030 (the furthest projected year estimated in this work).

Table 5-7. Summary of the US emission estimates by ship type for 1996 (tons/year).

Ship Type	HC	CO	NO_x	PM	SO₂
Bulk Carrier	1,461	5,906	45,196	2,668	18,812
Container Ship	2,360	5,797	38,404	3,125	23,881
General Cargo	478	2,060	16,078	996	6,940
Miscellaneous	179	1,066	5,914	245	1,552
Passenger	344	879	6,143	747	5,804
Reefer	257	756	4,160	263	1,952
Roro	140	567	4,830	421	3,114
Tanker	1,175	3,950	32,022	3,048	22,507
Vehicle Carrier	259	570	3,732	293	2,247
Total	6,650	21,529	156,478	11,794	86,763

Table 5-8. Summary of the US emission estimates by ship type for 2010 (tons/year).

Ship Type	HC	CO	NO_x	PM	SO₂
Bulk Carrier	1,985	8,051	57,170	3,617	25,441
Container Ship	5,288	12,937	80,251	6,339	47,191
General Cargo	578	2,451	17,876	1,184	8,237
Miscellaneous	253	1,579	8,244	348	2,183
Passenger	890	2,137	14,275	1,361	10,221
Reefer	363	1,056	5,385	373	2,769
Roro	187	737	5,919	517	3,794
Tanker	1,683	5,716	41,659	3,767	27,341
Vehicle Carrier	373	841	4,971	417	3,207
Total	10,581	33,745	229,307	17,386	125,979

Table 5-9. Summary of the US emission estimates by ship type for 2020 (tons/year).

Ship Type	HC	CO	NO_x	PM	SO₂
Bulk Carrier	2,543	10,333	69,366	4,627	32,494
Container Ship	9,497	23,193	135,672	10,964	80,734
General Cargo	685	2,867	19,934	1,385	9,617
Miscellaneous	332	2,116	10,592	456	2,854
Passenger	1,658	3,909	25,188	2,224	16,420
Reefer	475	1,375	6,620	489	3,638
Roro	238	918	7,042	620	4,518
Tanker	2,090	7,132	48,535	4,350	31,236
Vehicle Carrier	448	1,015	5,618	502	3,857
Total	15,325	48,268	312,933	24,243	174,226

Table 5-10. Summary of the US emission estimates by ship type for 2030 (tons/year).

Ship Type	HC	CO	NO_x	PM	SO₂
Bulk Carrier	3,291	13,391	87,354	5,980	41,945
Container Ship	17,216	42,014	237,971	19,431	142,121
General Cargo	827	3,425	23,133	1,654	11,466
Miscellaneous	439	2,848	13,897	604	3,769
Passenger	3,114	7,274	44,857	3,861	28,188
Reefer	626	1,804	8,415	646	4,803
Roro	305	1,160	8,686	757	5,487
Tanker	2,604	8,926	58,369	5,091	36,176
Vehicle Carrier	602	1,377	7,289	670	5,150
Total	23,169	71,958	456,772	35,692	254,950

6. SENSITIVITY ANALYSIS

INTRODUCTION

A sensitivity analysis was performed to demonstrate the effect of the uncertainty in the some of the estimates used to create the emissions inventory. The estimates tested and described below were adjusting the load estimates at intermediate speeds between stopped and cruise speeds, the emission factors of propulsion engines, the number of steamship port calls, the maximum and minimum load estimates for the cruise and auxiliary engine loads, and the emission factors during maneuvering modes only.

The emission estimates of each sensitivity analysis was compared with those estimates provided in Chapter 3 and also below in Tables 6-1 through 6-5. In each sensitivity case, we adjusted the assumptions used in the base emission estimates presented in Chapter 3 and carried them through the emissions calculations for the US ports. Because the States' of Texas and California estimates were used directly and not estimated in this work, the emission estimates for the Houston area and California ports were adjusted according to the average effect of the sensitivity analysis on all other ports.

Table 6-1. Baseline emission estimates for merchant vessels from Chapter 3 summed for all modes (tons/year).

Vessel Type	HC	CO	NO_x	PM	SO₂
Bulk Carrier	1,461	5,906	45,196	2,668	18,812
Container Ship	2,360	5,797	38,404	3,125	23,881
General Cargo	478	2,060	16,078	996	6,940
Miscellaneous	179	1,066	5,914	245	1,552
Passenger	344	879	6,143	747	5,804
Reefer	257	756	4,160	263	1,952
Roll-on Roll-off	140	567	4,830	421	3,114
Tanker	1,175	3,950	32,022	3,048	22,507
Vehicle Carrier	259	570	3,732	293	2,247
Total	6,650	21,529	156,478	11,794	86,763

Table 6-2. Baseline emission estimates for merchant vessels from Chapter 3 for cruise speed emissions (tons/year).

Vessel Type	HC	CO	NO_x	PM	SO₂
Bulk Carrier	204	415	8,909	684	5,083
Container Ship	202	407	8,648	762	5,577
General Cargo	70	130	2,850	235	1,742
Miscellaneous	11	18	410	38	283
Passenger	46	88	1,771	266	2,048
Reefer	14	29	626	47	349
Roll-on Roll-off	32	63	1,343	122	916
Tanker	142	300	6,116	697	5,329
Vehicle Carrier	18	34	749	58	430
Total	739	1,484	31,423	2,909	21,894

Table 6-3. Baseline emission estimates for merchant vessels from Chapter 3 for reduced speed zone (RSZ) emissions (tons/year).

Vessel Type	HC	CO	NO_x	PM	SO₂
Bulk Carrier	553	1,026	15,424	1,223	9,276
Container Ship	942	1,644	16,996	1,513	11,945
General Cargo	185	334	5,386	442	3,249
Miscellaneous	51	86	773	68	527
Passenger	124	211	2,020	208	1,656
Reefer	97	164	1,405	123	991
Roll-on Roll-off	48	93	1,468	145	1,116
Tanker	477	891	13,251	1,325	9,847
Vehicle Carrier	109	187	1,984	169	1,327
Total	2,587	4,635	58,707	5,215	39,936

Table 6-4. Baseline emission estimates for merchant vessels from Chapter 3 for maneuvering emissions (tons/year).

Vessel Type	HC	CO	NO_x	PM	SO₂
Bulk Carrier	362	994	1,931	218	1,238
Container Ship	703	1,894	2,204	294	1,462
General Cargo	95	259	451	54	301
Miscellaneous	43	120	128	18	90
Passenger	97	236	362	54	315
Reefer	81	220	233	33	155
Roll-on Roll-off	29	78	168	20	119
Tanker	275	728	1,404	183	1,116
Vehicle Carrier	80	218	241	33	161
Total	1,762	4,726	7,120	895	4,912

Table 6-5. Baseline emission estimates for merchant vessels from Chapter 3 for hotelling emissions (tons/year).

Vessel Type	HC	CO	NO_x	PM	SO₂
Bulk Carrier	343	3,472	18,932	543	3,181
Container Ship	512	1,853	10,557	556	4,755
General Cargo	128	1,336	7,391	265	1,639
Miscellaneous	73	842	4,603	121	650
Passenger	77	344	1,991	220	1,774
Reefer	66	342	1,895	60	458
Roll-on Roll-off	31	334	1,851	134	964
Tanker	281	2,031	11,247	842	6,180
Vehicle Carrier	52	130	753	32	325
Total	1,563	10,685	59,219	2,774	19,925

REDUCED SPEED ZONE AND MANEUVERING MODAL LOADS

In the course of interviewing knowledgeable sources (e.g. Rideout, 2001), we found it is possible or likely that on-board generator engines (mostly Category 2) run continuously in transit as well as at dock. In the equation for determining the engine load in the baseline emission estimates, an assumption was made that the propulsion power would have 10% load for auxiliary power and 80% total load at cruise speed (80% load at cruise is EPA guidance but that assumption is also supported by the Environment Canada data). Therefore, if auxiliary engines supply the 10% load for auxiliary power instead of the propulsion engines, then the load on the propulsion engines may be reduced for RSZ and maneuvering modes. So this sensitivity analysis provided emission estimates using the follow equation for loads at intermediate speeds;

$$\text{Load Fraction} = 0.8 * (\text{Speed}/\text{Cruise Speed})^3$$

instead of the baseline estimates using the following equation;

$$\text{Load Fraction} = 0.1 + 0.7 * (\text{Speed}/\text{Cruise Speed})^3$$

The auxiliary engine emissions increased because the 10% auxiliary load would occur during transit as well as hotelling modal operation to supply onboard electrical power. But the cruise emissions remained unchanged because the cruise load estimate of 80% was still used.

Not considered in this sensitivity analysis was that specific emission factors (in g/kW-hr units) at the lower load fractions (propulsion engine loads below 10% now occur at vessels speeds lower than about 7 knots for bulk carriers or about 11 knots for container ships for this sensitivity analysis) have been reported to increase significantly. The maneuvering mode was assumed (and confirmed by discussions with Harbor Pilots) to be 4 knots resulting in loads of 3% or less. This likely increase in the specific emission factors during maneuvering and some RSZ modes may cancel the effect of the reduced load calculated at slower vessel speeds.

The results shown in Tables 6-6 through 6-9 demonstrate that while overall emissions did not change significantly, RSZ and maneuvering modes emissions decreased, and auxiliary engine emissions increased. Cruise mode propulsion emissions were unchanged by this sensitivity analysis.

Table 6-6. Emissions with an alternative form of the load equation for all modes and ports (tons/year).

Vessel Type	HC	CO	NO_x	PM	SO₂
Bulk Carrier	1,112	5,421	44,670	2,418	17,105
Container Ship	1,646	4,392	36,624	2,665	21,266
General Cargo	389	2,044	16,461	932	6,469
Miscellaneous	141	1,001	6,075	233	1,492
Passenger	257	788	6,363	784	6,233
Reefer	157	540	3,783	201	1,551
Roll-on Roll-off	114	594	5,046	407	2,995
Tanker	926	3,765	32,112	2,953	22,033
Vehicle Carrier	193	402	3,593	248	2,037
Total	4,903	18,948	154,876	10,934	81,891
<i>Baseline Total</i>	<i>6,650</i>	<i>21,529</i>	<i>156,478</i>	<i>11,794</i>	<i>86,763</i>

Table 6-7. Emissions with an alternative form of the load equation for the RSZ mode of all ports (tons/year).

Vessel Type	HC	CO	NO_x	PM	SO₂
Bulk Carrier	482	894	13,430	1,067	8,095
Container Ship	655	1,144	11,828	1,045	8,248
General Cargo	160	289	4,651	383	2,814
Miscellaneous	47	80	707	62	488
Passenger	82	138	1,330	131	1,042
Reefer	65	109	937	82	662
Roll-on Roll-off	39	74	1,177	111	848
Tanker	396	742	10,969	1,108	8,277
Vehicle Carrier	87	149	1,584	135	1,060
Subtotal	2,100	3,765	47,680	4,232	32,407
<i>Baseline Subtotal</i>	<i>2,587</i>	<i>4,635</i>	<i>58,707</i>	<i>5,215</i>	<i>39,936</i>

Table 6-8. Emissions with an alternative form of the load equation for maneuvering of all ports (tons/year).

Vessel Type	HC	CO	NO_x	PM	SO₂
Bulk Carrier	27	71	286	30	180
Container Ship	12	26	112	13	72
General Cargo	6	15	59	6	38
Miscellaneous	2	4	17	2	11
Passenger	2	4	17	3	15
Reefer	2	3	14	2	9
Roll-on Roll-off	1	4	15	2	10
Tanker	16	42	173	22	138
Vehicle Carrier	2	4	15	2	10
Subtotal	77	186	777	89	518
<i>Baseline Subtotal</i>	<i>1,762</i>	<i>4,726</i>	<i>7,120</i>	<i>895</i>	<i>4,912</i>

Table 6-9. Emissions with an alternative form of the load equation for auxiliary engines at all ports (This now includes auxiliary engine emission during transit and hotelling modes.) (tons/year).

Vessel Type	HC	CO	NO_x	PM	SO₂
Bulk Carrier	399	4,042	22,044	636	3,744
Container Ship	778	2,815	16,036	845	7,232
General Cargo	154	1,610	8,901	308	1,873
Miscellaneous	80	900	4,942	131	709
Passenger	127	558	3,245	384	3,127
Reefer	76	398	2,205	70	532
Roll-on Roll-off	41	453	2,511	172	1,222
Tanker	371	2,682	14,851	1,125	8,279
Vehicle Carrier	86	215	1,240	53	535
Total	1,986	13,514	74,990	3,703	27,055
<i>Baseline Subtotal</i> <i>(Hotelling only)</i>	<i>1,563</i>	<i>10,685</i>	<i>59,219</i>	<i>2,774</i>	<i>19,925</i>

EMISSION FACTORS

There was considerable uncertainty in the specific NO_x and PM emission factors (in units of g/kW-hr) estimates because of the fuel type and specific combustion efficiency estimate employed to convert fuel-based emission factors (in units of kg/tonne). The emission factors determined as described in Chapter 1 and used to produce the baseline emission estimates as described in Chapter 3 were generally higher for NO_x and, depending upon fuel sulfur assumptions, either lower or higher in PM and SO₂ than previous comparable emission factors.

The NOx emission factors used in the baseline emissions estimates relied on the available data for specific fuel consumption in g/kW-hr units and emissions data in kg/tonne units. Therefore an error in either one will contribute to an error in the specific emissions rates in g/kW-hr units used in the emission estimates. For 2-stroke low speed Category 3 engines, the type most prevalent among merchant ships, manufacturers reported emission rates of 17 - 19 g/kW-hr though the test data indicated an average of 23.6 g/kW-hr. A value of 17 g/kW-hr reported by Lloyds (1995) was used for the sensitivity run as a lower limit for comparison purposes. For 4-stroke medium speed engines, Lloyds (1995) reported the NOx emission rate of 12 g/kW-hr instead of the value 16.6 g/kW-hr used in this study. If these lower Lloyds (1995) estimates are used, then no emission reductions can be expected for newer vessels meeting the MARPOL standard.

For PM the primary uncertainty is the sulfur level of the fuel used for propulsion and auxiliary engines. The sulfur level chosen for the heavy fuel used in the baseline estimates for propulsion engines was 3% by weight, while one report indicated that the sulfur can range from 0.8% to 3.92% worldwide with the US range from 1.8% to 3.9%. (Bunker fuel specifications found at <http://www.marinelink.com/members/stats/>) The PM emission rates were then recalculated based on the discussion in Chapter 1.

As expected, when the emission factors are changed, the overall emission estimates were proportionally affected as shown in Table 6-10. The emission changes primarily affect the transit emissions produced by propulsion engines, though steamships are thought to use residual fuel in the boilers while hotelling. Therefore a small portion of the PM and SO₂ emission increases were assumed to occur during hotelling, but the NOx decrease was assumed to occur only during transit modes.

Table 6-10. Effect of NOx emission factor and fuel sulfur assumptions on total port emissions (tons/year).

Comparison	NOx	PM	SO₂
Lower NOx Emission Rates	129,794	-	-
1% Sulfur Fuel	-	3,942	42,204
4% Sulfur Fuel	-	23,240	109,043
<i>Baseline</i>	<i>156,478</i>	<i>11,794</i>	<i>86,763</i>

STEAMSHIPS

It is likely that the current (1996 base year) numbers of steamships will dwindle as these older ships are retired because very few new steamships will be constructed. For instance, according to a report by the JIME (1999), only 4 out of 363 vessels constructed in Japan (the country that was the largest builder of merchant vessels in that year) in 1997 were steam turbine-powered.

A sensitivity analysis was run that converted the 1996 port calls of steamships entirely to diesel powered vessels of similar dead weight tonnage (DWT). As Table 6-11 shows, the emissions of NO_x, HC, and CO were higher and PM and SO₂ were lower by supplanting steamships with diesel powered vessels according to the emission rates for steamships compared to motorships.

Table 6-11. 1996 emissions with steamships replaced by diesel motor ships (tons/year).

Vessel Type	HC	CO	NO_x	PM	SO₂
Bulk Carrier	1,489	6,015	46,025	2,608	18,177
Container Ship	2,550	6,290	41,738	2,706	19,431
General Cargo	479	2,072	16,152	902	6,103
Miscellaneous	188	1,134	6,297	252	1,577
Passenger	465	1,167	8,165	510	3,620
Reefer	257	756	4,160	263	1,952
Roll-on Roll-off	141	567	4,894	285	1,976
Tanker	1,516	4,971	39,510	2,276	15,546
Vehicle Carrier	259	570	3,732	293	2,247
Total	7,377	23,642	171,022	10,109	70,240
<i>Baseline Total</i>	<i>6.650</i>	<i>21.529</i>	<i>156.478</i>	<i>11.794</i>	<i>86.763</i>

LOAD ASSUMPTIONS

Besides the issue of the which engines supply auxiliary load during transit is the uncertainty in the 10% auxiliary and 80% cruise load estimates. The 80% load at cruise is the historic EPA guidance but Environment Canada measured this load at anywhere from 70% to 99%.

The relative auxiliary load was based on the fraction of installed power as supplied by Lloyds registry data, so is highly uncertain given that ships with large propulsion engines may require not much more auxiliary power than smaller ships. A range of 5 to 15% auxiliary load is suggested for a sensitivity analysis. Also this load may be supplied only by Category 2 engines, so the sensitivity analysis of auxiliary load may not be relevant to Category 3 engine emissions.

Four sensitivity runs were performed using the load equations shown below.

- (1) An assumption for the cruise load of 100% and hotelling load of 10% was made and affected the cruise, RSZ, and maneuvering modal emissions through the equation shown below with results shown in Table 6-12.

$$\text{Load Fraction} = 0.1 + 0.9 * (\text{Speed}/\text{Cruise Speed})^3$$

Table 6-12. Case of 100% cruise load (tons/year).

Vessel Type	HC	CO	NO_x	PM	SO₂
Bulk Carrier	1,641	6,262	50,693	3,102	22,059
Container Ship	2,583	6,211	43,527	3,578	27,372
General Cargo	537	2,171	17,921	1,147	8,053
Miscellaneous	191	1,088	6,135	266	1,707
Passenger	374	932	6,858	843	6,544
Reefer	279	794	4,553	296	2,206
Roll-on Roll-off	159	602	5,459	479	3,555
Tanker	1,311	4,220	36,142	3,482	25,758
Vehicle Carrier	286	620	4,320	341	2,622
Total	7,388	22,939	175,868	13,545	100,014
<i>Baseline Total</i>	<i>6.650</i>	<i>21.529</i>	<i>156.478</i>	<i>11.794</i>	<i>86.763</i>

- (2) An assumption for the cruise load of 70% and hotelling load of 10% was made and affected the cruise, RSZ, and maneuvering modal emissions through the equation shown below with results shown in Table 6-13.

$$\text{Load Fraction} = 0.1 + 0.6 * (\text{Speed}/\text{Cruise Speed})^3$$

Table 6-13. Case of 70% cruise load (tons/year).

Vessel Type	HC	CO	NO_x	PM	SO₂
Bulk Carrier	1,371	5,728	42,448	2,451	17,188
Container Ship	2,248	5,590	35,843	2,898	22,136
General Cargo	448	2,005	15,157	920	6,383
Miscellaneous	173	1,056	5,804	235	1,474
Passenger	329	852	5,785	700	5,434
Reefer	247	736	3,964	247	1,826
Roll-on Roll-off	131	549	4,515	392	2,894
Tanker	1,107	3,815	29,962	2,832	20,881
Vehicle Carrier	245	545	3,438	268	2,059
Total	6,282	20,824	146,783	10,919	80,137
<i>Baseline Total</i>	<i>6.650</i>	<i>21.529</i>	<i>156.478</i>	<i>11.794</i>	<i>86.763</i>

- (3) An assumption of the cruise load of 80% and auxiliary load of 15% was made and affected the RSZ, maneuvering, and hotelling modal emissions through the equation shown below with results shown in Table 6-14.

$$\text{Load Fraction} = 0.15 + 0.65 * (\text{Speed}/\text{Cruise Speed})^3$$

Table 6-14. Case of 15% auxiliary load (tons/year).

Vessel Type	HC	CO	NO_x	PM	SO₂
Bulk Carrier	1,820	8,126	56,470	3,109	21,527
Container Ship	3,090	7,863	47,301	3,775	28,796
General Cargo	595	2,862	20,334	1,181	8,109
Miscellaneous	236	1,541	8,302	316	1,935
Passenger	450	1,199	7,654	921	7,152
Reefer	344	1,056	5,450	329	2,418
Roll-on Roll-off	173	778	5,977	514	3,784
Tanker	1,475	5,355	39,394	3,657	26,879
Vehicle Carrier	332	755	4,420	341	2,617
Total	8,447	29,377	194,722	14,066	102,690
<i>Baseline Total</i>	<i>6.650</i>	<i>21.529</i>	<i>156.478</i>	<i>11.794</i>	<i>86.763</i>

- (4) An assumption of the cruise load of 80% and auxiliary load of 5% was made and affected the RSZ, maneuvering, and hotelling modal emissions through the equation shown below with results shown in Table 6-15.

$$\text{Load Fraction} = 0.05 + 0.75 * (\text{Speed}/\text{Cruise Speed})^3$$

Table 6-15. Case of 5% auxiliary load (tons/year).

Vessel Type	HC	CO	NO_x	PM	SO₂
Bulk Carrier	1,102	3,687	33,922	2,227	16,097
Container Ship	1,630	3,732	29,508	2,475	18,966
General Cargo	361	1,258	11,822	810	5,770
Miscellaneous	122	592	3,526	174	1,169
Passenger	239	559	4,631	574	4,455
Reefer	171	455	2,870	197	1,487
Roll-on Roll-off	107	355	3,683	328	2,444
Tanker	875	2,545	24,649	2,439	18,135
Vehicle Carrier	185	386	3,044	244	1,876
Total	4,854	13,682	118,234	9,522	70,836
<i>Baseline Total</i>	<i>6.650</i>	<i>21.529</i>	<i>156.478</i>	<i>11.794</i>	<i>86.763</i>

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APPENDIX A

Detailed Ports Emissions

File Name

DetailedPortsEmissions03 with SO2.xls

														EMISSION FACTORS		
Cruise							RSZ							Maneuver		
g/hp-hr	Load	HC	CO	NOx	PM	SO2	g/hp-hr	HC	CO	NOx	PM	SO2	g/hp-hr			
	0.8															
	2	0.395	0.82	17.6	1.29	9.56	2	0.395	0.82	17.6	1.29	9.56	2			
	4	0.395	0.52	12.38	1.31	9.69	4	0.395	0.52	12.38	1.31	9.69	4			
Steam		0.05	0.22	2.09	1.86	15.0	Steam	0.05	0.22	2.09	1.86	15.0	Steam			
							Speed	6.5 knots					Speed			

For SO2 calcs:

	BSFC (g/hp-hr)	
2-stroke	253.7893025	163.3
4-stroke	260.1601133	165.5
Steam	255	255

Maneuverir

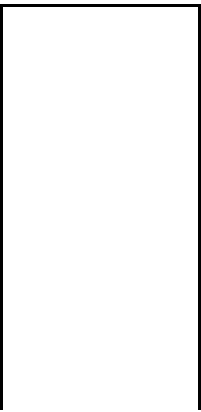
slow

medium

HC	CO	NOx	PM	SO2	Hotel g/hp-hr	Load HC	CO	NOx	PM	SO2	All Modes
2.085717	6.072741	23.9113	2.168337	23.02		2	0.1	1.85	9.96	0.239	1.07
2.172732	4.432346	16.87605	2.216072	23.87		4	0.1	1.85	9.96	0.239	1.07
0.05	0.22	2.09	1.86	15.0	Steam		0.05	0.22	2.09	1.86	1.65
4 knots											

g Adjustment

HC	CO	NOx	PM	CO2
5.28	7.41	1.36	1.68	1.55
5.500588	8.523742	1.36317	1.691658	1.571964



Lower Mississippi River Ports Emissions by Vessel Type (TPY)

EMISSIONS ESTIMATES																	
Vessel Type	Cruise HC	Cruise CO	Cruise NOx	Cruise PM	Cruise SO2	RSZ HC	RSZ CO	RSZ NOx	RSZ PM	RSZ SO2	Maneuvering HC	Maneuvering CO	Maneuvering NOx	Maneuvering PM	Maneuvering SO2	Hotelling HC	Hotelling CO
BARGE CARRIER	1	1	26	4	28	1	2	44	7	51	0	1	3	0	4	1	12
BULK CARRIER	68	139	2992	223	1651	93	192	4113	309	2289	24	69	271	25	266	70	1280
CONTAINER SHIP	5	10	206	25	194	6	13	255	32	247	2	6	24	3	31	3	43
GENERAL CARGO	8	14	313	25	185	18	35	761	60	446	4	10	38	4	39	8	155
MISCELLANEOUS	0	0	5	0	3	0	0	9	1	5	0	0	1	0	1	1	10
PASSENGER	3	6	114	13	102	4	9	182	22	169	1	3	12	2	15	1	14
REEFER	0	0	7	1	4	0	1	12	1	7	0	0	1	0	1	1	12
RORO	2	3	71	5	40	3	7	142	11	79	1	2	8	1	8	1	19
TANKER	21	43	930	72	532	61	124	2668	205	1525	12	33	129	12	129	17	307
VEHICLE CARRIER	0	0	1	0	1	0	0	4	0	2	0	0	0	0	0	0	1
Grand Total	107	218	4665	368	2741	188	382	8190	648	4820	43	123	487	47	495	101	1853

Lower Mississippi River Ports Emissions by Engine Type (TPY)

EMISSIONS ESTIMATES																	
	Cruise HC	Cruise CO	Cruise NOx	Cruise PM	Cruise SO2	RSZ HC	RSZ CO	RSZ NOx	RSZ PM	RSZ SO2	Maneuvering HC	Maneuvering CO	Maneuvering NOx	Maneuvering PM	Maneuvering SO2	Hotelling HC	Hotelling CO
2-stroke	99	206	4421	324	2401	172	358	7676	563	4169	40	116	457	41	440	91	1688
4-stroke	7	9	204	22	160	14	18	439	46	343	3	7	25	3	36	8	144
Steam Engine	1	2	24	21	169	1	4	40	36	289	0	0	2	2	17	2	7
Grand Total	107	218	4665	368	2741	188	382	8190	648	4820	43	123	487	47	495	101	1853

New York Ports Emissions by Vessel Type (TPY)

EMISSIONS ESTIMATES																	
Vessel Type	Cruise HC	Cruise CO	Cruise NOx	Cruise PM	Cruise SO2	RSZ HC	RSZ CO	RSZ NOx	RSZ PM	RSZ SO2	Maneuvering HC	Maneuvering CO	Maneuvering NOx	Maneuvering PM	Maneuvering SO2	Hotelling HC	Hotelling CO
BARGE CARRIER	0	0	1	1	6	0	0	0	0	2	0	0	0	0	1	0	1
BULK CARRIER	5	10	215	17	128	6	12	249	19	143	3	8	32	3	32	6	110
CONTAINER SHIP	38	80	1683	155	1171	15	32	660	61	461	13	36	144	15	155	12	210
GENERAL CARGO	3	7	149	12	89	2	5	98	8	58	1	4	15	1	15	3	38
MISCELLANEOUS	0	0	3	0	2	0	0	2	0	2	0	0	0	0	0	0	1
PASSENGER	5	8	164	24	181	2	4	82	12	94	2	4	17	3	27	1	12
REEFER	1	2	38	3	21	0	1	15	1	8	0	1	3	0	3	0	8
RORO	4	8	182	14	101	2	4	87	6	48	2	6	24	2	24	2	31
TANKER	16	33	703	64	479	11	23	484	44	333	13	36	143	15	153	9	165
VEHICLES CARRIER	5	9	188	15	109	2	4	91	7	53	2	6	25	2	26	1	19
Grand Total	77	157	3325	304	2286	41	84	1769	160	1201	36	102	404	42	436	34	595

New York Ports Emissions by Engine Type (TPY)

EMISSIONS ESTIMATES																	
	Cruise HC	Cruise CO	Cruise NOx	Cruise PM	Cruise SO2	RSZ HC	RSZ CO	RSZ NOx	RSZ PM	RSZ SO2	Maneuvering HC	Maneuvering CO	Maneuvering NOx	Maneuvering PM	Maneuvering SO2	Hotelling HC	Hotelling CO
2-stroke	67	139	2983	219	1620	36	74	1592	117	865	32	93	365	33	351	28	519
4-stroke	9	12	280	30	219	5	6	146	15	114	4	9	33	4	47	3	63
Steam Engine	1	7	62	56	447	1	3	31	28	222	0	1	5	5	38	3	13
Grand Total	77	157	3325	304	2286	41	84	1769	160	1201	36	102	404	42	436	34	595

Delaware River Ports Emissions by Vessel Type (TPY)

EMISSIONS ESTIMATES																	
Vessel Type	Cruise HC	Cruise CO	Cruise NOx	Cruise PM	Cruise SO2	RSZ HC	RSZ CO	RSZ NOx	RSZ PM	RSZ SO2	Maneuvering HC	Maneuvering CO	Maneuvering NOx	Maneuvering PM	Maneuvering SO2	Hotelling HC	Hotelling CO
BULK CARRIER	5	11	238	18	131	10	20	420	31	231	2	6	23	2	23	5	90
CONTAINER SHIP	6	11	235	19	138	6	12	268	21	157	2	5	18	2	19	2	43
GENERAL CARGO	3	6	127	10	77	5	10	215	17	129	1	3	12	1	13	3	50
MISCELLANEOUS	0	0	1	0	1	0	0	2	0	1	0	0	0	0	0	0	0
PASSENGER	0	0	9	2	18	0	0	8	2	20	0	0	1	0	2	0	1
REEFER	3	6	136	10	76	4	7	155	12	86	1	3	13	1	13	2	42
RORO	1	1	21	2	14	1	1	30	3	19	0	0	1	0	2	0	6
TANKER	14	29	607	53	397	24	51	1071	94	702	8	23	89	9	93	13	227
VEHICLE CARRIER	1	2	39	3	22	1	1	31	2	18	0	1	3	0	3	0	4
Grand Total	33	66	1413	117	873	51	103	2200	183	1363	14	41	161	16	168	26	465

Delaware River Ports Emissions by Engine Type (TPY)

EMISSIONS ESTIMATES																	
	Cruise HC	Cruise CO	Cruise NOx	Cruise PM	Cruise SO2	RSZ HC	RSZ CO	RSZ NOx	RSZ PM	RSZ SO2	Maneuvering HC	Maneuvering CO	Maneuvering NOx	Maneuvering PM	Maneuvering SO2	Hotelling HC	Hotelling CO
2-stroke	28	59	1267	93	688	45	93	1999	147	1086	13	37	148	13	142	23	417
4-stroke	4	6	135	14	105	6	8	182	19	142	2	3	12	2	17	2	44
Steam Engine	0	1	11	10	80	0	2	19	17	135	0	0	1	1	9	1	3
Grand Total	33	66	1413	117	873	51	103	2200	183	1363	14	41	161	16	168	26	465

Puget Sound Ports Emissions by Vessel Type (TPY)

EMISSIONS ESTIMATES																	
Vessel Type	Cruise HC	Cruise CO	Cruise NOx	Cruise PM	Cruise SO2	RSZ HC	RSZ CO	RSZ NOx	RSZ PM	RSZ SO2	Maneuvering HC	Maneuvering CO	Maneuvering NOx	Maneuvering PM	Maneuvering SO2	Hotelling HC	Hotelling CO

BULK CARRIER	10	21	452	34	256	0	36	75	1605	124	925	4	11	43	4	43	11	208
CONTAINER SHIP	27	57	1194	112	845	0	62	132	2747	255	1927	7	21	85	9	91	12	203
FISHING	1	1	17	2	17	0	2	3	65	9	67	0	1	4	1	6	3	50
GENERAL CARGO	3	7	142	11	84	0	11	21	466	38	280	1	3	12	1	13	3	46
MISCELLANEOUS	0	0	2	0	2	0	0	1	11	1	11	0	0	0	0	0	1	14
PASSENGER	0	0	10	1	8	0	1	1	24	3	20	0	0	1	0	1	0	3
REEFER	0	1	16	1	9	0	1	2	50	4	29	0	1	3	0	3	1	15
RORO	1	3	39	14	109	0	2	6	79	33	260	0	0	3	1	10	2	9
TANKER	4	11	190	47	370	0	13	34	575	145	1143	4	11	47	11	100	4	45
VEHICLES CARRIER	2	4	77	6	44	0	6	11	233	18	135	1	2	6	1	6	0	8
Grand Total	49	104	2140	229	1745		134	285	5857	629	4796	17	50	204	28	273	37	600

Puget Sound Ports Emissions by Engine Type (TPY)

EMISSIONS ESTIMATES																	
	Cruise HC	Cruise CO	Cruise NOx	Cruise PM	Cruise SO2	RSZ HC	RSZ CO	RSZ NOx	RSZ PM	RSZ SO2	Maneuvering HC	Maneuvering CO	Maneuvering NOx	Maneuvering PM	Maneuvering SO2	Hotelling HC	Hotelling CO
2-stroke	44	92	1980	145	1075	120	250	5367	393	2915	16	46	183	17	176	27	496
4-stroke	2	3	75	8	59	8	11	256	27	200	1	3	10	1	14	4	79
Steam Engine	2	9	85	76	611	6	25	235	209	1681	0	1	12	10	84	6	25
Grand Total	49	104	2140	229	1745	134	285	5857	629	4796	17	50	204	28	273	37	600

Port of Corpus Christi Emissions by Vessel Type (TPY)

EMISSIONS ESTIMATES																		
Vessel Type	Cruise HC	Cruise CO	Cruise NOx	Cruise PM	Cruise SO2	RSZ HC	RSZ CO	RSZ NOx	RSZ PM	RSZ SO2	Maneuvering HC	Maneuvering CO	Maneuvering NOx	Maneuvering PM	Maneuvering SO2	Hotelling HC	Hotelling CO	
BARGE CARRIER	0	0	0	0	2	#	0	0	0	0	1	0	0	0	0	0	0	
BULK CARRIER	3	6	139	10	77	0	2	4	90	7	50	2	6	24	2	23	1	26
CONTAINER SHIP	0	0	2	0	1	0	0	0	1	0	1	0	0	1	0	1	0	1
TANKER	13	29	574	78	600	0	8	18	355	47	364	8	24	98	13	125	5	75
GENERAL CARGO	0	0	3	0	3	0	0	0	2	0	2	0	0	0	0	1	0	1
MISCELLANEOUS	0	0	1	0	1	#	0	0	1	0	0	0	0	0	0	0	0	0
Grand Total	17	36	720	89	684		10	22	449	54	418	11	31	123	15	150	6	103

Port of Corpus Christi Emissions by Engine Type (TPY)

EMISSIONS ESTIMATES																	
	Cruise HC	Cruise CO	Cruise NOx	Cruise PM	Cruise SO2	RSZ HC	RSZ CO	RSZ NOx	RSZ PM	RSZ SO2	Maneuvering HC	Maneuvering CO	Maneuvering NOx	Maneuvering PM	Maneuvering SO2	Hotelling HC	Hotelling CO
2-stroke	14	30	634	47	345	9	19	400	29	217	10	28	112	10	108	5	87
4-stroke	1	2	43	5	33	1	1	24	3	19	1	2	6	1	9	1	11
Steam Engine	1	4	43	38	306	1	3	25	23	181	0	0	5	4	33	1	5

Grand Total	17	36	720	89	684	10	22	449	54	418	11	31	123	15	150	6	103
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Port of Tampa Emissions by Vessel Type (TPY)

Vessel Type	EMISSIONS ESTIMATES															Hotelling HC	Hotelling CO
	Cruise HC	Cruise CO	Cruise NOx	Cruise PM	Cruise SO2	RSZ HC	RSZ CO	RSZ NOx	RSZ PM	RSZ SO2	Maneuvering HC	Maneuvering CO	Maneuvering NOx	Maneuvering PM	Maneuvering SO2		
BULK CARRIER	7	14	299	24	175	4	7	155	12	90	4	10	41	4	41	5	90
CONTAINER SHIP	0	0	4	0	2	0	0	2	0	1	0	0	1	0	1	0	3
GENERAL CARGO	2	3	70	6	46	1	2	39	3	26	1	1	5	1	6	1	20
PASSENGER	3	6	127	10	73	1	3	63	5	36	1	2	9	1	9	1	21
REEFER	0	1	20	1	11	0	0	7	0	4	0	1	2	0	2	0	9
RORO	0	0	5	0	3	0	0	3	0	2	0	0	1	0	1	0	3
TANKER	4	8	157	20	157	2	4	83	11	82	1	3	12	2	17	1	21
TUG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VEHICLES CARRIER	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1
BARGE DRY CARGO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BARGE TANKER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MISCELLANEOUS	0	0	2	0	2	0	0	1	0	1	0	0	0	0	0	0	6
UNSPECIFIED MOTOR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grand Total	17	32	685	63	469	9	16	353	32	241	7	18	71	7	77	10	174

Port of Tampa Emissions by Engine Type (TPY)

	EMISSIONS ESTIMATES															Hotelling HC	Hotelling CO
	Cruise HC	Cruise CO	Cruise NOx	Cruise PM	Cruise SO2	RSZ HC	RSZ CO	RSZ NOx	RSZ PM	RSZ SO2	Maneuvering HC	Maneuvering CO	Maneuvering NOx	Maneuvering PM	Maneuvering SO2		
2-stroke	9	19	403	30	219	5	10	208	15	113	4	12	49	4	47	5	94
4-stroke	1	1	23	2	18	0	0	11	1	9	0	0	2	0	3	1	16
Steam Engine	0	1	10	9	72	0	1	5	5	37	0	0	1	1	5	0	2
Grand Total	17	32	685	63	469	9	16	353	32	241	7	18	71	7	77	10	174

Port of Baltimore by Vessel Type (TPY)

Vessel Type	EMISSIONS ESTIMATES															Hotelling HC	Hotelling CO
	Cruise HC	Cruise CO	Cruise NOx	Cruise PM	Cruise SO2	RSZ HC	RSZ CO	RSZ NOx	RSZ PM	RSZ SO2	Maneuvering HC	Maneuvering CO	Maneuvering NOx	Maneuvering PM	Maneuvering SO2		
BULK CARRIER	7	14	302	24	182	31	64	1354	108	809	2	6	25	2	25	6	111
CONTAINER SHIP	11	24	510	40	299	31	66	1397	110	817	4	13	50	5	49	3	52
GENERAL CARGO	2	4	85	7	52	9	17	363	30	225	1	2	8	1	8	2	35
MISCELLANEOUS	0	0	3	0	2	0	1	16	2	11	0	0	0	0	0	1	13
PASSENGER	0	0	9	2	12	1	1	20	4	29	0	0	1	0	1	0	5
REEFER	0	0	1	0	1	0	0	2	0	1	0	0	0	0	0	0	3

RORO	4	9	186	14	101	13	27	586	43	320	2	5	19	2	19	2	32
TANKER	2	3	70	6	45	7	14	291	25	191	1	2	6	1	7	1	13
VEHICLES CARRIER	4	7	155	12	90	10	20	434	34	253	2	5	19	2	20	1	19
Grand Total	30	62	1321	105	784	102	209	4463	356	2656	11	33	129	12	130	16	283

Port of Baltimore Emissions by Engine Type (TPY)

EMISSIONS ESTIMATES																	
	Cruise HC	Cruise CO	Cruise NOx	Cruise PM	Cruise SO2	RSZ HC	RSZ CO	RSZ NOx	RSZ PM	RSZ SO2	Maneuvering HC	Maneuvering CO	Maneuvering NOx	Maneuvering PM	Maneuvering SO2	Hotelling HC	Hotelling CO
2-stroke	28	58	1248	91	678	95	196	4217	309	2290	11	31	122	11	117	13	244
4-stroke	2	3	65	7	51	7	9	219	23	171	1	2	6	1	9	2	37
Steam Engine	0	1	8	7	55	1	3	27	24	194	0	0	1	0	4	1	2
Grand Total	30	62	1321	105	784	102	209	4463	356	2656	11	33	129	12	130	16	283

Coos Bay Emissions by Vessel Type (TPY)

EMISSIONS ESTIMATES																	
Vessel Type	Cruise HC	Cruise CO	Cruise NOx	Cruise PM	Cruise SO2	RSZ HC	RSZ CO	RSZ NOx	RSZ PM	RSZ SO2	Maneuvering HC	Maneuvering CO	Maneuvering NOx	Maneuvering PM	Maneuvering SO2	Hotelling HC	Hotelling CO
BULK CARRIER	2	4	76	6	41	0	1	16	1	9	0	1	3	0	2	1	21
GENERAL CARGO	1	1	30	2	16	0	0	6	0	3	0	0	1	0	1	0	8
MISCELLANEOUS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grand Total	2	5	106	8	58	1	1	23	2	12	0	1	4	0	3	2	29

Coos Bay Emissions by Engine Type (TPY)

EMISSIONS ESTIMATES																	
	Cruise HC	Cruise CO	Cruise NOx	Cruise PM	Cruise SO2	RSZ HC	RSZ CO	RSZ NOx	RSZ PM	RSZ SO2	Maneuvering HC	Maneuvering CO	Maneuvering NOx	Maneuvering PM	Maneuvering SO2	Hotelling HC	Hotelling CO
2-stroke	2	5	106	8	57	1	1	23	2	12	0	1	4	0	3	2	28
4-stroke	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Steam Engine	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grand Total	2	5	106	8	58	1	1	23	2	12	0	1	4	0	3	2	29

Port of Cleveland Emissions by Vessel Type (TPY)

EMISSIONS ESTIMATES																	
Vessel Type	Cruise HC	Cruise CO	Cruise NOx	Cruise PM	Cruise SO2	RSZ HC	RSZ CO	RSZ NOx	RSZ PM	RSZ SO2	Maneuvering HC	Maneuvering CO	Maneuvering NOx	Maneuvering PM	Maneuvering SO2	Hotelling HC	Hotelling CO
BULK CARRIER, SALTY	0	1	16	1	9	0	0	3	0	2	0	1	5	0	5	1	15
BULK CARRIER, LAKER	1	3	60	5	41	0	1	15	1	10	5	13	51	5	55	0	0

CONTAINER SHIP, SALTY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EXCURSION VESSEL	0	0	0	0	0	0	0	12	1	9	0	0	1	0	1	0	0
GENERAL CARGO, SALTY	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1
TANKER, SALTY	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grand Total	2	4	77	7	50	1	1	31	3	22	5	15	58	6	62	1	17

Port of Cleveland Emissions by Engine Type (TPY)

EMISSIONS ESTIMATES																	
	Cruise HC	Cruise CO	Cruise NOx	Cruise PM	Cruise SO2	RSZ HC	RSZ CO	RSZ NOx	RSZ PM	RSZ SO2	Maneuvering HC	Maneuvering CO	Maneuvering NOx	Maneuvering PM	Maneuvering SO2	Hotelling HC	Hotelling CO
2-stroke	1	3	63	5	34	0	1	15	1	8	4	12	47	4	45	1	16
4-stroke	0	1	13	1	10	0	1	15	2	12	1	3	11	1	15	0	1
Steam Engine	0	0	1	1	6	0	0	0	0	1	0	0	0	0	2	0	0
Grand Total	2	4	77	7	50	1	1	31	3	22	5	15	58	6	62	1	17

Burns Waterway Harbor Emissions by Vessel Type (TPY)

EMISSIONS ESTIMATES																	
Vessel Type	Cruise HC	Cruise CO	Cruise NOx	Cruise PM	Cruise SO2	RSZ HC	RSZ CO	RSZ NOx	RSZ PM	RSZ SO2	Maneuvering HC	Maneuvering CO	Maneuvering NOx	Maneuvering PM	Maneuvering SO2	Hotelling HC	Hotelling CO
BULK CARRIER, SALTY	0	0	10	1	6	0	0	2	0	1	0	1	3	0	3	0	5
BULK CARRIER, LAKER	1	1	23	2	14	0	0	5	0	3	1	1	5	1	6	0	1
GENERAL CARGO, SALTY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TANKER, SALTY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grand Total	1	2	34	3	20	0	0	8	1	5	1	2	9	1	9	0	6

Burns Waterway Harbor Emissions by Engine Type (TPY)

EMISSIONS ESTIMATES																	
	Cruise HC	Cruise CO	Cruise NOx	Cruise PM	Cruise SO2	RSZ HC	RSZ CO	RSZ NOx	RSZ PM	RSZ SO2	Maneuvering HC	Maneuvering CO	Maneuvering NOx	Maneuvering PM	Maneuvering SO2	Hotelling HC	Hotelling CO
2-stroke	1	1	31	2	17	0	0	7	1	4	1	2	8	1	8	0	6
4-stroke	0	0	3	0	2	0	0	1	0	1	0	0	1	0	1	0	0
Steam Engine	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Grand Total	1	2	34	3	20	0	0	8	1	5	1	2	9	1	9	0	6

Lower Mississippi River F

Vessel Type	Hotelling NOx	Hotelling PM	Hotelling SO2	All Modes HC	All Modes CO	All Modes NOx	All Modes PM	All Modes SO2
BARGE CARRIER	68	11	86	3	16	140	22	170
BULK CARRIER	6901	181	865	254	1680	14277	737	5071
CONTAINER SHIP	240	23	170	16	72	724	84	643
GENERAL CARGO	838	22	108	38	214	1950	111	778
MISCELLANEOUS	54	1	6	1	11	68	3	15
PASSENGER	78	7	52	9	32	386	44	338
REEFER	65	2	7	1	13	85	3	18
RORO	102	2	11	7	31	323	19	138
TANKER	1654	45	222	111	506	5381	334	2408
VEHICLE CARRIER	4	0	0	0	1	10	1	4
Grand Total	10002	296	1527	439	2576	23344	1358	9583

Lower Mississippi River F

	Hotelling NOx	Hotelling PM	Hotelling SO2	All Modes HC	All Modes CO	All Modes NOx	All Modes PM	All Modes SO2
2-stroke	9089	218	974	403	2368	21642	1146	7983
4-stroke	774	19	83	32	178	1443	90	622
Steam Engine	64	57	462	3	14	131	116	937
Grand Total	10002	296	1527	439	2576	23344	1358	9583

Transit Modes HC	Transit Modes CO	Transit Modes NOx	Transit Modes PM	Transit Modes SO2	
311	680	12,553	928	7,009	Slow
24	34	669	71	539	Medium
3	14	131	116	937	Steamship
99	1,832	9,863	237	1,057	category 2
total	437	2,559	23,215	1,352	9,543

New York Ports Emission

Vessel Type	Hotelling NOx	Hotelling PM	Hotelling SO2	All Modes HC	All Modes CO	All Modes NOx	All Modes PM	All Modes SO2
BARGE CARRIER	9	8	65	0	1	10	9	73
BULK CARRIER	594	16	79	19	140	1091	56	381
CONTAINER SHIP	1150	68	454	78	358	3636	300	2241
GENERAL CARGO	217	33	252	10	53	479	54	414
MISCELLANEOUS	5	0	1	0	1	11	1	5
PASSENGER	69	6	41	10	28	332	45	343
REEFER	42	1	4	2	11	98	5	36
RORO	170	14	96	10	49	463	36	269
TANKER	898	40	243	49	258	2228	162	1208
VEHICLES CARRIER	102	2	11	10	38	406	27	199
Grand Total	3257	188	1246	189	938	8755	694	5170

New York Ports Emission

	Hotelling NOx	Hotelling PM	Hotelling SO2	All Modes HC	All Modes CO	All Modes NOx	All Modes PM	All Modes SO2
2-stroke	2793	67	299	163	825	7733	435	3136
4-stroke	337	8	36	21	89	796	58	416
Steam Engine	127	113	911	5	24	225	201	1618
Grand Total	3257	188	1246	189	938	8755	694	5170

Transit Modes HC	Transit Modes CO	Transit Modes NOx	Transit Modes PM	Transit Modes SO2	
135	306	4,940	368	2,836	Slow
18	27	459	49	380	Medium
5	24	225	201	1,618	Steamship
31	581	3,130	75	336	category 2
total	189	938	8,755	694	5,170

Delaware River Ports Emi

Vessel Type	Hotelling NOx	Hotelling PM	Hotelling SO2	All Modes HC	All Modes CO	All Modes NOx	All Modes PM	All Modes SO2
BULK CARRIER	484	12	53	22	127	1166	63	437
CONTAINER SHIP	233	6	25	16	71	754	47	339
GENERAL CARGO	270	6	29	12	69	623	35	247
MISCELLANEOUS	1	0	0	0	0	4	0	2
PASSENGER	8	2	16	1	2	25	7	56
REEFER	228	5	24	10	59	531	29	199
RORO	33	1	4	2	9	86	5	38
TANKER	1234	55	339	59	329	3002	210	1532
VEHICLE CARRIER	24	1	3	2	8	96	6	45
Grand Total	2515	88	493	124	674	6288	403	2896

Delaware River Ports Emi

	Hotelling NOx	Hotelling PM	Hotelling SO2	All Modes HC	All Modes CO	All Modes NOx	All Modes PM	All Modes SO2
2-stroke	2244	54	241	109	606	5658	307	2156
4-stroke	239	6	26	14	61	568	41	291
Steam Engine	32	28	226	2	7	63	56	449
Grand Total	2515	88	493	124	674	6288	403	2896

Transit Modes HC	Transit Modes CO	Transit Modes NOx	Transit Modes PM	Transit Modes SO2	
86	190	3,414	253	1,916	Slow
12	16	329	35	265	Medium
2	7	63	56	449	Steamship
25	461	2,483	60	266	category 2
total	124	674	6,288	403	2,896

Puget Sound Ports Emiss

Vessel Type	Hotelling NOx	Hotelling PM	Hotelling SO2	All Modes HC	All Modes CO	All Modes NOx	All Modes PM	All Modes SO2
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BULK CARRIER	1122	30	142	62	315	3223	192	1366
CONTAINER SHIP	1115	70	474	108	413	5141	446	3336
FISHING	275	23	161	6	54	361	34	252
GENERAL CARGO	249	6	31	19	77	869	57	408
MISCELLANEOUS	73	2	10	1	14	87	4	23
PASSENGER	16	1	7	1	5	50	5	36
REEFER	79	2	8	3	18	149	7	50
RORO	76	55	440	4	18	197	102	819
TANKER	285	93	737	25	101	1098	296	2349
VEHICLES CARRIER	44	1	5	8	24	360	26	190
Grand Total	3334	283	2015	237	1041	11535	1170	8830

Puget Sound Ports Emiss

	Hotelling NOx	Hotelling PM	Hotelling SO2	All Modes HC	All Modes CO	All Modes NOx	All Modes PM	All Modes SO2
2-stroke	2672	64	286	208	885	10201	619	4453
4-stroke	428	10	46	16	96	768	46	318
Steam Engine	234	209	1683	14	60	566	504	4059
Grand Total	3334	283	2015	237	1041	11535	1170	8830

Transit Modes HC	Transit Modes CO	Transit Modes NOx	Transit Modes PM	Transit Modes SO2	
181	389	7,530	555	4,166	Slow
12	16	340	36	272	Medium
14	60	566	504	4,059	Steamship
31	576	3,100	74	332	category 2
total	237	1,041	11,535	1,170	8,830

Port of Corpus Christi Em

Vessel Type	Hotelling NOx	Hotelling PM	Hotelling SO2	All Modes HC	All Modes CO	All Modes NOx	All Modes PM	All Modes SO2
BARGE CARRIER	1	1	7	0	0	1	1	10
BULK CARRIER	138	3	15	9	42	391	23	166
CONTAINER SHIP	4	0	0	0	1	7	0	3
TANKER	423	47	350	35	146	1450	185	1439
GENERAL CARGO	4	0	1	0	1	10	1	6
MISCELLANEOUS	1	0	0	0	0	3	0	1
Grand Total	571	52	373	44	191	1863	210	1624

Port of Corpus Christi Em

	Hotelling NOx	Hotelling PM	Hotelling SO2	All Modes HC	All Modes CO	All Modes NOx	All Modes PM	All Modes SO2
2-stroke	469	11	50	38	164	1615	97	720
4-stroke	58	1	6	4	15	131	9	68
Steam Engine	44	39	317	3	12	117	104	837

Transit Modes HC	Transit Modes CO	Transit Modes NOx	Transit Modes PM	Transit Modes SO2	
33	77	1,146	86	669	Slow
3	5	74	8	62	Medium
3	12	117	104	837	Steamship

Grand Total	571	52	373	44	191	1863	210	1624
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total 5 98 527 13 57 **category 2**
44 191 1,863 210 1,624

Port of Tampa Emissions

Vessel Type	Hotelling NOx	Hotelling PM	Hotelling SO2	All Modes HC	All Modes CO	All Modes NOx	All Modes PM	All Modes SO2
BULK CARRIER	487	12	57	20	122	981	52	363
CONTAINER SHIP	17	0	2	0	4	24	1	6
GENERAL CARGO	107	3	15	4	26	222	13	93
PASSENGER	115	3	12	6	32	314	18	130
REEFER	46	1	6	1	10	75	3	23
RORO	16	0	2	0	3	25	1	8
TANKER	121	17	127	8	36	373	50	383
TUG	0	0	0	0	0	0	0	0
VEHICLES CARRIER	5	0	1	0	1	7	0	1
BARGE DRY CARGO	0	0	0	0	0	0	0	0
BARGE TANKER	0	0	0	0	0	0	0	0
MISCELLANEOUS	32	1	3	0	6	36	1	6
UNSPECIFIED MOTOR	0	0	0	0	0	0	0	0
Grand Total	946	38	225	41	241	2055	140	1013

Port of Tampa Emissions

	Hotelling NOx	Hotelling PM	Hotelling SO2	All Modes HC	All Modes CO	All Modes NOx	All Modes PM	All Modes SO2
2-stroke	503	12	54	23	134	1164	61	433
4-stroke	89	2	10	2	18	125	6	40
Steam Engine	17	15	125	1	4	33	30	239
Grand Total	946	38	225	41	241	2055	140	1013

Transit Modes HC 18
Transit Modes CO 41
Transit Modes NOx 660
Transit Modes PM 49
Transit Modes SO2 379 Slow
1 2 36 4 30 Medium
1 4 33 30 239 Steamship
6 110 592 14 64 **category 2**
total 26 156 1,322 97 713

Port of Baltimore by Vess

Vessel Type	Hotelling NOx	Hotelling PM	Hotelling SO2	All Modes HC	All Modes CO	All Modes NOx	All Modes PM	All Modes SO2
BULK CARRIER	600	18	91	46	195	2281	153	1107
CONTAINER SHIP	281	10	53	50	154	2238	164	1219
GENERAL CARGO	192	11	69	13	58	648	49	354
MISCELLANEOUS	68	2	7	1	14	88	4	22
PASSENGER	31	7	54	1	7	61	12	96
REEFER	15	0	2	0	3	19	1	3

RORO	174	4	19	21	73	966	63	458
TANKER	68	2	14	10	31	436	35	257
VEHICLES CARRIER	101	2	11	17	51	709	51	373
Grand Total	1532	56	320	160	586	7444	530	3889

Port of Baltimore Emissio

	Hotelling NOx	Hotelling PM	Hotelling SO2	All Modes HC	All Modes CO	All Modes NOx	All Modes PM	All Modes SO2
2-stroke	1311	31	141	146	529	6898	443	3226
4-stroke	199	5	21	12	51	490	36	253
Steam Engine	22	20	158	1	6	57	51	410
Grand Total	1532	56	320	160	586	7444	530	3889

Transit Modes HC	Transit Modes CO	Transit Modes NOx	Transit Modes PM	Transit Modes SO2	
133	285	5,586	412	3,085	Slow
10	14	291	31	232	Medium
1	6	57	51	410	Steamship
15	280	1,510	36	162	category 2
total 160	586	7,444	530	3,889	

Coos Bay Emissions by V

Vessel Type	Hotelling NOx	Hotelling PM	Hotelling SO2	All Modes HC	All Modes CO	All Modes NOx	All Modes PM	All Modes SO2
BULK CARRIER	110	3	12	3	25	205	10	65
GENERAL CARGO	42	1	5	1	10	79	4	25
MISCELLANEOUS	1	0	0	0	0	2	0	1
Grand Total	154	4	16	5	36	287	14	90

Coos Bay Emissions by E

	Hotelling NOx	Hotelling PM	Hotelling SO2	All Modes HC	All Modes CO	All Modes NOx	All Modes PM	All Modes SO2
2-stroke	152	4	16	5	35	284	13	89
4-stroke	2	0	0	0	0	3	0	1
Steam Engine	0	0	0	0	0	0	0	0
Grand Total	154	4	16	5	36	287	14	90

Transit Modes HC	Transit Modes CO	Transit Modes NOx	Transit Modes PM	Transit Modes SO2	
3	7	132	10	73	Slow
0	0	1	0	1	Medium
0	0	0	0	0	Steamship
2	29	154	4	16	category 2
total 5	36	287	14	90	

Port of Cleveland Emissic

Vessel Type	Hotelling NOx	Hotelling PM	Hotelling SO2	All Modes HC	All Modes CO	All Modes NOx	All Modes PM	All Modes SO2
BULK CARRIER, SALTY	82	2	9	2	17	106	4	24
BULK CARRIER, LAKER	0	0	0	7	16	126	12	106

CONTAINER SHIP, SALTY	1	0	0	0	0	1	0	0
EXCURSION VESSEL	0	0	0	0	1	13	1	11
GENERAL CARGO, SALTY	7	0	1	0	1	8	0	2
TANKER, SALTY	0	0	0	0	0	1	0	1
Grand Total	90	2	10	9	36	255	18	143

Port of Cleveland Emissic

	Hotelling NOx	Hotelling PM	Hotelling SO2	All Modes HC	All Modes CO	All Modes NOx	All Modes PM	All Modes SO2
2-stroke	87	2	9	7	32	212	12	97
4-stroke	3	0	0	2	5	42	4	38
Steam Engine	0	0	0	0	0	1	1	9
Grand Total	90	2	10	9	36	255	18	143

total

Transit Modes HC	Transit Modes CO	Transit Modes NOx	Transit Modes PM	Transit Modes SO2	
6	15	125	10	87	Slow
2	4	39	4	37	Medium
0	0	1	1	9	Steamship
1	17	90	2	10	category 2
9	36	255	18	143	

Burns Waterway Harbor E

Vessel Type	Hotelling NOx	Hotelling PM	Hotelling SO2	All Modes HC	All Modes CO	All Modes NOx	All Modes PM	All Modes SO2
BULK CARRIER, SALTY	27	1	5	1	6	43	2	15
BULK CARRIER, LAKER	3	0	1	1	3	37	3	23
GENERAL CARGO, SALTY	1	0	0	0	0	2	0	1
TANKER, SALTY	0	0	0	0	0	1	0	1
Grand Total	32	1	6	2	10	82	5	39

Burns Waterway Harbor E

	Hotelling NOx	Hotelling PM	Hotelling SO2	All Modes HC	All Modes CO	All Modes NOx	All Modes PM	All Modes SO2
2-stroke	30	1	3	2	9	76	4	32
4-stroke	1	0	0	0	1	6	0	4
Steam Engine	0	0	3	0	0	1	0	4
Grand Total	32	1	6	2	10	82	5	39

total

Transit Modes HC	Transit Modes CO	Transit Modes NOx	Transit Modes PM	Transit Modes SO2	
2	4	46	4	28	Slow
0	0	4	0	4	Medium
0	0	1	0	4	Steamship
0	6	31	1	3	category 2
2	10	82	5	39	

Lower Mississippi River F

Vessel Type
BARGE CARRIER
BULK CARRIER
CONTAINER SHIP
GENERAL CARGO
MISCELLANEOUS
PASSENGER
REEFER
RORO
TANKER
VEHICLE CARRIER
Grand Total

Lower Mississippi River F

2-stroke
4-stroke
Steam Engine
Grand Total

New York Ports Emission

Vessel Type
BARGE CARRIER
BULK CARRIER
CONTAINER SHIP
GENERAL CARGO
MISCELLANEOUS
PASSENGER
REEFER
RORO
TANKER
VEHICLES CARRIER
Grand Total

New York Ports Emission

2-stroke
4-stroke
Steam Engine
Grand Total

Delaware River Ports Emi

Vessel Type
BULK CARRIER
CONTAINER SHIP
GENERAL CARGO
MISCELLANEOUS
PASSENGER
REEFER
RORO
TANKER
VEHICLE CARRIER
Grand Total

Delaware River Ports Emi

2-stroke
4-stroke
Steam Engine
Grand Total

Puget Sound Ports Emiss

Vessel Type

BULK CARRIER
CONTAINER SHIP
FISHING
GENERAL CARGO
MISCELANEOUS
PASSENGER
REEFER
RORO
TANKER
VEHICLES CARRIER
Grand Total

Puget Sound Ports Emiss

2-stroke
4-stroke
Steam Engine
Grand Total

Port of Corpus Christi Em

Vessel Type
BARGE CARRIER
BULK CARRIER
CONTAINER SHIP
TANKER
GENERAL CARGO
MISCELLANEOUS
Grand Total

Port of Corpus Christi Em

2-stroke
4-stroke
Steam Engine

Grand Total

Port of Tampa Emissions

Vessel Type
BULK CARRIER
CONTAINER SHIP
GENERAL CARGO
PASSENGER
REEFER
RORO
TANKER
TUG
VEHICLES CARRIER
BARGE DRY CARGO
BARGE TANKER
MISCELLANEOUS
UNSPECIFIED MOTOR
Grand Total

Port of Tampa Emissions

2-stroke
4-stroke
Steam Engine
Grand Total

Port of Baltimore by Vess

Vessel Type
BULK CARRIER
CONTAINER SHIP
GENERAL CARGO
MISCELLANEOUS
PASSENGER
REEFER

RORO
TANKER
VEHICLES CARRIER
Grand Total

Port of Baltimore Emissio

2-stroke
4-stroke
Steam Engine
Grand Total

Coos Bay Emissions by V

Vessel Type
BULK CARRIER
GENERAL CARGO
MISCELLANEOUS
Grand Total

Coos Bay Emissions by E

2-stroke
4-stroke
Steam Engine
Grand Total

Port of Cleveland Emissio

Vessel Type
BULK CARRIER, SALTY
BULK CARRIER, LAKER

CONTAINER SHIP, SALTY
EXCURSION VESSEL
GENERAL CARGO, SALTY
TANKER, SALTY
Grand Total

Port of Cleveland Emissic

2-stroke
4-stroke
Steam Engine
Grand Total

Burns Waterway Harbor E

Vessel Type
BULK CARRIER, SALTY
BULK CARRIER, LAKER
GENERAL CARGO, SALTY
TANKER, SALTY
Grand Total

Burns Waterway Harbor E

2-stroke
4-stroke
Steam Engine
Grand Total

Table 6-6: Summary of 1996 Deep-Sea Vessel Data for the Lower Mississippi River

Ship Type	Engine Type	DWT Range	Calls	DWT (Tonnes)	Power (hp)	Vessel Speed (knots)	Engine Speed (RPM)	% RPM >130	Date of Build	Cruise (hr/call)	RSZ (hr/call)	Maneuver (hr/call)	Hotel (hr/call)
BARGE CARRIER	2	35,000 - 45,000	9	44,799	26,100	18	ND	ND	1972	2.8	18.3	1.7	80.1
BARGE CARRIER	2	> 45,000	10	49,835	26,000	18	ND	ND	1969	2.8	18.6	1.6	81.4
BARGE CARRIER	ST	35,000 - 45,000	10	41,578	31,565	22	ND	ND	1974	2.3	18.2	1.8	107.7
BARGE CARRIER	ST	> 45,000	6	47,036	31,565	22	ND	ND	1975	2.3	18.8	1.9	76.7
BARGE CARRIER	0		0	45,701	28,570	20	ND	ND	1972	2.3	19.9	2.5	134.0
BARGE CARRIER Total			38	45,701	28,570	20	#N/A	#N/A	1972	2.5	18.6	1.8	91.4
BULK CARRIER	2	<25,000	438	18,138	8,060	15	140	39%	1979	3.4	20.7	2.4	144.7
BULK CARRIER	2	25,000 - 35,000	717	29,492	10,768	15	132	51%	1978	3.3	19.9	2.5	172.9
BULK CARRIER	2	35,000 - 45,000	507	39,596	11,266	15	114	15%	1982	3.4	20.8	2.5	153.8
BULK CARRIER	2	> 45,000	1,183	72,142	14,501	15	98	0%	1984	7.8	18.4	2.7	195.2
BULK CARRIER	4	<25,000	70	15,614	6,606	14	479	100%	1975	3.5	21.7	2.4	124.7
BULK CARRIER	4	25,000 - 35,000	13	27,092	9,528	14	278	100%	1987	3.5	21.5	2.6	193.2
BULK CARRIER	4	35,000 - 45,000	10	38,731	12,650	16	464	100%	1981	3.3	21.6	2.7	252.9
BULK CARRIER	4	> 45,000	26	63,419	13,531	14	342	73%	1983	3.5	16.9	2.8	200.2
BULK CARRIER	ST	<25,000	5	18,314	8,384	15	123	21%	1975	5.0	14.1	1.9	81.7
BULK CARRIER	ST	25,000 - 35,000	1	33,373	11,837	15	123	21%	1983	3.3	35.1	2.5	38.7
BULK CARRIER	ST	> 45,000	21	54,624	17,614	18	123	21%	1970	2.9	16.2	2.7	198.4
BULK CARRIER	0		0	46,560	11,904	15	123	21%	1981	3.7	20.4	2.5	206.7
BULK CARRIER Total			3,001	46,560	11,904	15	123	21%	1981	5.1	19.6	2.6	173.9
CONTAINER SHIP	2	<25,000	120	18,707	15,717	19	117	27%	1987	2.7	14.6	1.7	58.4
CONTAINER SHIP	2	25,000 - 35,000	6	28,019	19,411	19	111	0%	1984	2.8	14.5	2.0	66.6
CONTAINER SHIP	2	35,000 - 45,000	66	38,743	27,387	21	91	0%	1987	2.5	12.9	1.8	25.5
CONTAINER SHIP	2	> 45,000	4	53,726	28,845	19	97	0%	1985	3.1	13.1	1.8	30.0
CONTAINER SHIP	4	<25,000	84	10,063	12,157	17	425	100%	1991	2.8	12.8	1.6	20.5
CONTAINER SHIP	ST	<25,000	58	21,711	25,280	22	242	53%	1974	2.3	12.4	1.7	28.7
CONTAINER SHIP	ST	25,000 - 35,000	37	26,803	32,787	22	242	53%	1974	2.3	12.8	1.6	31.8
CONTAINER SHIP	ST	35,000 - 45,000	1	38,656	31,565	21	242	53%	1971	2.3	18.5	1.5	250.8
CONTAINER SHIP	0		0	22,127	20,366	20	242	53%	1984	3.5	12.7	2.8	190.0
CONTAINER SHIP Total			379	22,127	20,366	20	242	53%	1984	2.6	13.4	1.7	38.6
GENERAL CARGO	2	<15,000	247	9,246	6,166	15	178	91%	1981	3.5	19.9	2.2	141.7
GENERAL CARGO	2	15,000 - 30,000	265	20,223	11,344	16	134	30%	1982	3.1	19.0	2.0	88.4
GENERAL CARGO	2	30,000 - 45,000	41	40,358	12,943	15	97	0%	1983	3.3	22.9	2.2	84.2
GENERAL CARGO	2	> 45,000	4	46,648	14,313	17	105	0%	1995	3.0	13.9	1.9	32.8
GENERAL CARGO	4	<15,000	308	5,180	3,047	12	493	100%	1979	4.1	20.2	2.2	193.2
GENERAL CARGO	4	15,000 - 30,000	43	18,775	8,922	15	460	100%	1979	3.3	21.1	2.2	138.1
GENERAL CARGO	ST	15,000 - 30,000	2	22,536	23,673	21	212	64%	1969	3.0	16.8	3.0	230.8

Table 6-6: Summary of 1996 Deep-Sea Vessel Data for the Lower Mississippi River

Ship Type	Engine Type	DWT Range	Calls	DWT (Tonnes)	Power (hp)	Vessel Speed (knots)	Engine Speed (RPM)	% RPM >130	Date of Build	Cruise (hr/call)	RSZ (hr/call)	Maneuver (hr/call)	Hotel (hr/call)
GENERAL CARGO	0	0	1	13,112	7,128	15	212	64%	1980	3.6	15.2	2.5	24.9
GENERAL CARGO Total			911	13,112	7,128	15	212	64%	1980	3.6	19.9	2.1	140.4
MISCELLANEOUS	2	<1500	1	879	3,000	12	ND	ND	1978	4.2	36.8	2.5	1276.3
MISCELLANEOUS	2	> 4,500	1	9,360	10,330	18	ND	ND	1980	2.8	19.7	1.5	1072.3
MISCELLANEOUS	4	<1500	11	878	3,478	14	ND	ND	1980	3.9	11.4	2.0	502.4
MISCELLANEOUS	4	> 4,500	1	9,950	13,800	15	ND	ND	1982	3.3	13.0	1.5	234.7
MISCELLANEOUS	0	0	7	2,132	4,670	14	ND	ND	1980	5.0	17.2	2.7	355.5
MISCELLANEOUS Total			21	2,132	4,670	14	#N/A	#N/A	1980	4.2	14.9	2.2	512.1
PASSENGER	2	<5,000	26	4,217	29,370	21	363	53%	1983	2.4	18.7	1.7	25.5
PASSENGER	2	5,000 - 10,000	54	6,473	30,083	19	363	53%	1985	2.6	18.7	1.5	16.9
PASSENGER	2	> 15,000	9	19,830	14,726	18	102	0%	1988	2.8	11.5	1.6	36.1
PASSENGER	4	<5,000	4	1,358	9,167	17	750	100%	1967	3.1	18.5	1.9	188.5
PASSENGER	4	5,000 - 10,000	7	6,620	36,706	20	533	100%	1991	2.6	18.7	1.6	26.7
PASSENGER	ST	5,000 - 10,000	52	8,721	25,504	23	363	53%	1958	2.4	18.5	1.5	20.3
PASSENGER Total			152	7,519	27,240	21	363	53%	1976	2.5	18.2	1.6	25.7
REEFER	2	5,000 - 10,000	5	8,467	10,440	18	141	50%	1982	2.9	16.3	1.9	251.1
REEFER	2	10,000 - 15,000	8	11,457	14,812	20	123	0%	1980	2.6	18.1	1.6	383.5
REEFER	4	<5,000	1	4,196	4,400	15	128	14%	1981	3.3	10.9	3.0	186.9
REEFER Total			14	9,871	12,507	19	128	14%	1980	2.8	17.0	1.8	322.2
RORO	2	<5,000	4	4,613	6,100	17	451	86%	1979	3.0	19.4	1.5	89.4
RORO	2	5,000 - 10,000	7	6,521	7,014	17	451	86%	1983	3.0	19.2	1.9	120.7
RORO	2	10,000 - 15,000	10	12,777	11,512	17	157	100%	1989	3.0	16.6	2.1	192.2
RORO	2	> 15,000	45	37,027	27,881	19	102	0%	1982	2.8	19.7	1.8	44.9
RORO	4	<5,000	8	3,262	3,336	12	1800	100%	1980	4.0	18.4	2.2	101.7
RORO	4	5,000 - 10,000	26	9,883	5,998	14	500	100%	1984	3.4	13.0	1.8	25.5
RORO Total			100	21,412	16,259	17	451	86%	1983	3.1	17.5	1.8	66.2
TANKER	2	<30,000	314	16,943	7,930	15	168	76%	1984	3.4	25.9	2.5	81.8
TANKER	2	30,000 - 60,000	304	40,559	12,593	15	111	2%	1984	3.3	21.7	2.5	91.6
TANKER	2	60,000 - 90,000	303	77,606	15,455	15	97	0%	1984	3.4	27.0	2.4	71.0
TANKER	2	90,000 - 120,000	287	97,851	15,067	15	95	0%	1990	3.4	27.5	2.4	66.6
TANKER	2	120,000 - 150,000	49	134,806	23,453	15	99	0%	1983	3.3	10.4	1.9	76.3
TANKER	2	> 150,000	4	157,345	19,605	14	85	0%	1992	3.5	19.8	2.5	107.7
TANKER	4	<30,000	103	9,575	5,240	14	414	74%	1981	3.7	23.1	2.6	79.8
TANKER	4	30,000 - 60,000	19	46,237	15,072	16	132	20%	1979	3.2	25.2	2.6	454.9
TANKER	4	60,000 - 90,000	53	81,275	14,394	15	296	58%	1982	3.4	25.3	2.4	66.2
TANKER	ST	30,000 - 60,000	10	40,102	15,190	16	132	20%	1967	3.2	25.7	2.7	96.0
TANKER	ST	60,000 - 90,000	3	71,694	19,728	16	132	20%	1971	3.1	14.0	2.3	73.9
TANKER	ST	90,000 - 120,000	3	92,809	24,167	16	132	20%	1977	3.0	26.6	2.7	73.1
TANKER	ST	120,000 - 150,000	1	122,249	25,647	16	132	20%	1973	3.1	29.0	2.5	134.5
TANKER	0	0	5	57,586	12,699	15	132	20%	1985	3.4	16.5	2.5	143.7
TANKER Total			1,458	57,586	12,699	15	132	20%	1985	3.4	24.7	2.4	83.0
TUG	2	< 1,000	3	669	6,717	15	ND	ND	1978	3.4	18.4	2.2	280.2
TUG	2	< 500	28	6	3,631	12	ND	ND	1970	4.3	18.7	2.5	558.6
TUG	4	< 500	4	0	3,628	13	ND	ND	1966	3.9	17.7	2.8	1420.6
TUG	0	0	44	62	3,895	13	ND	ND	1970	4.0	14.1	2.6	847.7
TUG Total			79	62	3,895	13	#N/A	#N/A	1970	4.1	16.1	2.6	752.7
VEHICLE CARRIER	2	> 35,000	2	40,999	14,000	15	ND	ND	ND	3.3	26.4	2.5	117.3
VEHICLE CARRIER Total			2	40,999	14,000	15	#N/A	#N/A	#N/A	3.3	26.4	2.5	117.3

Table 6-6: Summary of 1996 Deep-Sea Vessel Data for the Lower Mississippi River

Ship Type	Engine Type	DWT Range	Calls	DWT (Tonnes)	Power (hp)	Vessel Speed (knots)	Engine Speed (RPM)	% RPM >130	Date of Build	Cruise (hr/call)	RSZ (hr/call)	Maneuver (hr/call)	Hotel (hr/call)
Grand Total			6,155	40,829	12,393	15	154	30%	1982	4.2	20.3	2.4	142.1

Table 7-5: Summary of 1996 Deep-Sea Vessel Data for the Consolidated Port of New York and Ports on the Hudson River

Ship Type	Stroke	DWT Category	Calls	DWT (tonnes)	Power (hp)	Vessel Speed (knots)	Engine Speed (RPM)	%RPM >130	Date of Build	Cruise (hr/call)	RSZ (hr)	Man. (hr)	Hotel (hr)
BARGE CARRIER	ST	35,000 - 45,000	6	46,153	31,541	22	ND	ND	1974	2.3	3.4	1.6	209.4
BARGE CARRIER Total			6	46,153	31,541	22	ND	ND	1974	2.3	3.4	1.6	209.4
BULK CARRIER	2	<25,000	69	19,957	8,666	15	152	62%	1982	3.3	14.3	2.2	120.0
BULK CARRIER	2	25,000 - 35,000	85	29,401	10,766	15	130	63%	1979	3.3	11.6	2.6	184.6
BULK CARRIER	2	35,000 - 45,000	64	39,241	10,891	15	118	10%	1982	3.4	14.8	2.4	102.0
BULK CARRIER	2	> 45,000	122	71,583	14,107	14	102	0%	1986	3.5	5.9	2.9	115.6
BULK CARRIER	4	<25,000	16	18,260	6,523	15	573	100%	1979	3.4	7.3	2.7	219.2
BULK CARRIER	4	25,000 - 35,000	1	25,739	8,200	14	157	100%	1992	3.6	4.9	1.3	104.4
BULK CARRIER	4	35,000 - 45,000	1	41,513	10,000	14	ND	ND	1982	3.6	2.4	5.0	226.2
BULK CARRIER	4	> 45,000	4	70,719	12,075	14	ND	ND	1980	3.6	4.6	2.5	83.1
BULK CARRIER	ST	<25,000	28	18,314	8,378	15	ND	ND	1975	3.3	5.6	1.3	39.9
BULK CARRIER Total			390	41,733	11,119	15	132	24%	1982	3.4	10.1	2.5	127.5
CONTAINER SHIP	2	<25,000	396	20,258	16,922	19	117	10%	1987	2.7	4.2	1.2	24.9
CONTAINER SHIP	2	25,000 - 35,000	167	30,162	22,994	20	102	0%	1984	2.6	4.1	1.2	22.3
CONTAINER SHIP	2	35,000 - 45,000	348	40,772	40,589	23	99	0%	1982	2.2	4.2	1.1	19.7
CONTAINER SHIP	2	> 45,000	491	51,853	38,622	22	95	0%	1988	2.3	4.2	1.1	22.2
CONTAINER SHIP	4	<25,000	92	9,833	8,018	17	481	100%	1989	3.0	4.2	1.1	22.1
CONTAINER SHIP	4	25,000 - 35,000	5	27,396	15,962	18	386	100%	1980	2.7	4.0	1.4	16.0
CONTAINER SHIP	4	> 45,000	24	62,685	50,235	24	99	0%	1993	2.1	4.2	1.1	31.0
CONTAINER SHIP	ST	<25,000	234	20,521	25,642	22	ND	ND	1971	2.3	4.1	1.1	25.5
CONTAINER SHIP	ST	25,000 - 35,000	33	26,207	31,541	22	ND	ND	1973	2.3	4.2	1.1	20.5
CONTAINER SHIP	ST	35,000 - 45,000	14	39,433	35,483	25	ND	ND	1976	2.0	4.1	1.1	15.7
CONTAINER SHIP	ST	> 45,000	16	47,864	79,967	23	ND	ND	1973	2.2	4.2	1.1	16.2
CONTAINER SHIP Total			1,820	34,197	29,929	21	131	10%	1984	2.4	4.2	1.1	22.7
GENERAL CARGO	2	<15,000	49	11,029	7,586	16	146	25%	1986	3.2	4.3	1.9	70.3
GENERAL CARGO	2	15,000 - 30,000	122	20,397	13,611	17	132	32%	1982	2.9	6.5	1.7	54.6
GENERAL CARGO	2	30,000 - 45,000	54	39,365	13,689	15	ND	ND	1981	3.2	4.7	1.5	21.1
GENERAL CARGO	2	> 45,000	2	46,865	10,345	15	111	0%	1993	3.3	4.5	2.1	29.7
GENERAL CARGO	4	<15,000	79	5,539	3,765	13	616	100%	1987	3.9	7.0	1.7	78.9
GENERAL CARGO	4	15,000 - 30,000	11	19,019	8,896	17	ND	ND	1982	3.0	7.6	1.9	124.3
GENERAL CARGO	ST	<15,000	9	12,931	14,746	19	ND	ND	1962	2.6	4.0	1.3	1060.7
GENERAL CARGO Total			326	18,440	10,184	16	336	58%	1983	3.3	5.9	1.7	81.4
MISCELLANEOUS	2	<1500	2	24,713	2,200	12	ND	ND	1968	4.2	21.1	4.3	146.4
MISCELLANEOUS	2	> 4,500	2	23,945	9,000	16	ND	ND	1987	3.1	5.2	2.3	77.6
MISCELLANEOUS	4	<1500	18	11,783	2,320	14	ND	ND	1987	3.6	4.7	1.6	53.7
MISCELLANEOUS	4	> 4,500	1	5,009	13,581	14	720	100%	1992	3.6	2.3	0.5	1.5
MISCELLANEOUS Total			23	13,670	5,860	14	720	100%	1985	3.6	6.1	1.9	61.5
PASSENGER	2	<5,000	26	4,300	29,370	21	ND	ND	1984	2.4	5.2	1.3	6.3
PASSENGER	2	5,000 - 10,000	4	5,830	19,500	19	ND	ND	1971	2.7	5.2	1.3	15.6
PASSENGER	4	<5,000	22	1,896	15,080	18	646	100%	1987	2.9	6.0	1.5	24.1
PASSENGER	4	5,000 - 10,000	97	6,467	21,809	19	588	100%	1974	2.7	5.2	1.4	8.8
PASSENGER	4	10,000 - 15,000	1	8,600	86,140	18	514	100%	1996	2.8	5.2	1.3	72.1
PASSENGER	4	> 15,000	19	15,521	130,005	28	ND	ND	1969	1.8	5.2	1.3	8.1
PASSENGER	ST	5,000 - 10,000	14	9,102	41,479	25	ND	ND	1963	2.0	5.2	1.3	10.5
PASSENGER	ST	10,000 - 15,000	1	13,960	40,177	18	ND	ND	1961	2.8	5.2	1.3	6.2
PASSENGER	ST	> 15,000	43	16,604	43,369	24	ND	ND	1961	2.1	5.1	1.3	7.8
PASSENGER Total			227	8,648	36,700	21	600	100%	1973	2.4	5.2	1.4	10.2
REEFER	2	5,000 - 10,000	3	9,864	14,865	22	ND	ND	1980	2.3	4.7	0.8	24.9
REEFER	2	10,000 - 15,000	60	11,757	16,661	22	114	0%	1988	2.3	4.4	1.2	36.9
REEFER	2	> 15,000	1	15,100	20,500	22	ND	ND	1979	2.3	4.7	0.5	8.2
REEFER Total			64	11,721	16,637	22	114	0%	1987	2.3	4.4	1.1	35.8

Table 7-5: Summary of 1996 Deep-Sea Vessel Data for the Consolidated Port of New York and Ports on the Hudson River

Ship Type	Stroke	DWT Category	Calls	DWT (tonnes)	Power (hp)	Vessel Speed (knots)	Engine Speed (RPM)	%RPM >130	Date of Build	Cruise (hr/call)	RSZ (hr)	Man. (hr)	Hotel (hr)
RORO	2	<10,000	73	16,968	11,478	17	97	0%	1981	3.0	4.4	1.8	28.2
RORO	2	10,000 - 20,000	13	15,302	11,338	16	159	100%	1990	3.1	4.5	1.7	25.5
RORO	2	20,000 - 30,000	3	23,242	20,271	19	ND	ND	1981	2.6	4.2	4.1	277.1
RORO	2	> 30,000	119	46,217	25,750	19	97	0%	1983	2.7	4.7	2.1	17.0
RORO	4	<10,000	14	5,979	7,851	15	425	100%	1977	3.3	7.5	2.0	93.7
RORO	4	20,000 - 30,000	1	20,303	25,920	19	ND	ND	1971	2.6	4.0	1.3	1490.5
RORO	ST	10,000 - 20,000	1	15,946	29,570	24	ND	ND	1970	2.1	3.2	3.2	1625.7
RORO Total			224	31,817	19,088	18	104	3%	1982	2.9	4.7	2.0	43.2
TANKER	2	<30,000	202	22,271	8,766	15	135	27%	1985	3.4	6.1	3.4	45.6
TANKER	2	30,000 - 60,000	489	34,820	12,546	15	117	7%	1985	3.4	6.3	3.9	61.6
TANKER	2	60,000 - 90,000	155	74,752	15,612	15	101	0%	1984	3.3	5.8	3.6	64.5
TANKER	2	90,000 - 120,000	81	95,769	13,993	14	98	0%	1991	3.5	6.1	3.2	62.6
TANKER	2	120,000 - 150,000	31	140,266	20,709	15	86	0%	1987	3.4	4.4	2.7	72.3
TANKER	2	> 150,000	9	137,489	20,940	14	85	0%	1991	3.6	6.3	3.2	72.2
TANKER	4	<30,000	65	15,402	7,551	15	351	65%	1984	3.4	5.6	3.1	29.5
TANKER	4	30,000 - 60,000	21	43,052	14,917	16	ND	ND	1979	3.2	5.5	3.3	57.0
TANKER	4	60,000 - 90,000	29	71,780	13,598	14	256	39%	1985	3.5	6.2	3.7	58.8
TANKER	ST	<30,000	14	26,459	14,784	18	ND	ND	1964	2.8	5.4	3.2	26.4
TANKER	ST	30,000 - 60,000	82	36,889	15,108	16	ND	ND	1964	3.1	6.1	3.6	50.1
TANKER	ST	60,000 - 90,000	2	63,000	19,713	16	ND	ND	1971	3.1	5.6	3.9	85.4
TANKER	ST	> 150,000	23	35,605	35,293	16	ND	ND	1975	3.1	5.5	2.6	23.8
TANKER Total			1,203	45,538	13,120	15	128	12%	1983	3.4	6.0	3.6	56.0
VEHICLES CARRIER	2	<12,500	76	11,461	11,243	18	119	6%	1982	2.8	5.1	1.6	13.9
VEHICLES CARRIER	2	12,500 - 15,000	73	13,788	13,961	19	107	0%	1986	2.7	4.9	1.9	17.7
VEHICLES CARRIER	2	15,000 - 17,500	72	17,041	13,984	18	113	0%	1985	2.7	4.8	1.9	15.7
VEHICLES CARRIER	2	> 17,500	54	22,727	16,382	19	106	0%	1985	2.6	4.9	2.3	22.9
VEHICLES CARRIER	4	<12,500	51	10,566	13,240	18	518	100%	1980	2.7	5.0	2.2	30.0
VEHICLES CARRIER	4	12,500 - 15,000	19	13,498	14,287	18	520	100%	1980	2.9	4.9	1.9	24.7
VEHICLES CARRIER	4	15,000 - 17,500	2	15,396	12,555	18	ND	ND	1982	2.8	4.9	1.3	6.1
VEHICLES CARRIER	4	> 17,500	2	19,422	16,880	18	ND	ND	1981	2.8	5.1	2.1	6.8
VEHICLES CARRIER Total			349	14,890	13,670	18	178	18%	1984	2.7	4.9	2.0	19.3
Grand Total			4,632	33,449	20,932	18	162	18%	1983	2.8	5.4	2.0	45.0

Table 8-5: Summary of 1996 Deep-Sea Vessel Data for the Delaware River Ports Including Philadelphia, PA

Ship Type	Engine Type	DWT Range	Calls	DWT (tonnes)	Power (HP)	Vessel Speed (knots)	Engine Speed (RPM)	%RPM >130	Date of Build	Cruise (hr/call)	RSZ (hr/call)	Maneuver (hr/call)	Hotel (hr/call)
BULK CARRIER	2	<25,000	109	18,365	9,665	14	144	68%	1981	3.5	14.9	1.8	81.0
BULK CARRIER	2	25,000 - 35,000	126	29,721	9,696	15	126	52%	1982	3.4	14.7	1.7	100.8
BULK CARRIER	2	35,000 - 45,000	77	38,659	10,320	14	113	11%	1983	3.5	15.2	1.8	95.1
BULK CARRIER	2	> 45,000	81	79,616	16,328	15	113	0%	1983	3.4	15.3	1.7	110.9
BULK CARRIER	4	<25,000	17	13,853	7,504	15	473	100%	1977	3.3	14.4	1.6	86.3
BULK CARRIER	ST	<25,000	1	18,314	8,300	15	131	36%	1975	3.3	12.3	1.5	64.3
BULK CARRIER Total			411	40,274	11,018	15	131	36%	1982	3.4	14.9	1.7	95.8
CONTAINER SHIP	2	<25,000	242	18,425	17,757	19	106	0%	1987	2.6	11.4	1.2	37.4
CONTAINER SHIP	2	25,000 - 35,000	27	27,503	16,327	18	229	38%	1977	2.8	12.9	1.0	35.7
CONTAINER SHIP	4	<25,000	129	12,143	10,898	18	429	100%	1989	2.8	12.5	1.2	25.8
CONTAINER SHIP Total			398	18,208	15,383	19	229	38%	1987	2.7	11.9	1.1	33.5
GENERAL CARGO	2	<15,000	132	6,833	5,784	14	437	89%	1985	3.7	13.3	1.4	63.0
GENERAL CARGO	2	15,000 - 30,000	90	18,918	10,456	16	140	63%	1980	3.2	14.6	2.0	119.3
GENERAL CARGO	2	30,000 - 45,000	8	38,907	12,876	14	96	0%	1981	3.5	12.3	1.2	62.3
GENERAL CARGO	2	> 45,000	1	46,956	12,170	14	117	0%	1992	3.6	12.4	1.0	33.0
GENERAL CARGO	4	<15,000	166	5,316	3,944	14	743	100%	1988	3.7	12.9	1.6	98.1
GENERAL CARGO	4	15,000 - 30,000	16	18,775	7,536	15	561	90%	1981	3.4	15.1	1.7	122.6
GENERAL CARGO	ST	<15,000	1	10,538	6,284	14	561	90%	1918	3.6	14.2	1.0	18.1
GENERAL CARGO Total			414	10,538	6,284	14	561	90%	1985	3.6	13.4	1.6	91.3
MISCELLANEOUS	2	< 1,000	8	0	2,400	14	ND	ND	1943	3.6	10.9	1.2	45.4
MISCELLANEOUS	4	< 1,000	4	448	1,293	14	ND	ND	1978	3.6	12.4	1.4	41.1
MISCELLANEOUS Total			12	149	2,031	14	#N/A	#N/A	1955	3.6	11.4	1.3	44.0
PASSENGER	4	<5,000	6	1,332	16,108	18	532	100%	1983	2.9	11.4	1.0	24.3
PASSENGER	4	5,000 - 10,000	6	7,257	20,776	18	616	100%	1966	2.7	11.4	1.0	23.4
PASSENGER	ST	5,000 - 10,000	9	9,076	40,649	26	582	100%	1964	2.0	12.6	1.0	15.9
PASSENGER	ST	10,000 - 15,000	1	13,016	169,708	30	582	100%	1952	1.7	5.5	3.5	20.5
PASSENGER Total			22	7,828	34,403	22	582	100%	1969	2.4	11.6	1.1	20.5
REEFER	2	<5,000	28	4,988	9,553	18	146	65%	1984	2.7	10.7	1.6	51.4
REEFER	2	5,000 - 10,000	87	7,667	9,706	18	141	59%	1988	2.7	10.7	1.3	56.8
REEFER	2	10,000 - 15,000	153	11,833	12,500	19	116	0%	1987	2.6	12.2	1.4	64.8
REEFER	2	> 15,000	3	15,696	18,467	20	155	41%	1979	2.6	11.4	1.3	33.6

Table 8-5: Summary of 1996 Deep-Sea Vessel Data for the Delaware River Ports Including Philadelphia, PA

Ship Type	Engine Type	DWT Range	Calls	DWT (tonnes)	Power (HP)	Vessel Speed (knots)	Engine Speed (RPM)	%RPM >130	Date of Build	Cruise (hr/call)	RSZ (hr/call)	Maneuver (hr/call)	Hotel (hr/call)
REEFER	4	<5,000	16	4,880	7,048	16	202	100%	1992	3.1	13.6	2.5	87.8
REEFER	4	5,000 - 10,000	15	6,555	6,837	17	402	100%	1989	3.0	13.0	1.9	81.7
REEFER	4	10,000 - 15,000	3	11,087	15,672	22	428	100%	1992	2.3	11.2	1.0	54.0
REEFER Total			305	10,137	10,958	19	155	41%	1987	2.7	11.7	1.5	63.0
RORO	2	<15,000	26	7,074	8,280	17	242	100%	1981	2.9	13.2	1.2	67.1
RORO	2	15,000 - 30,000	5	22,845	12,852	18	102	0%	1988	2.8	8.8	1.0	43.0
RORO	4	<15,000	26	7,601	8,553	14	720	100%	1981	3.7	13.3	1.2	57.7
RORO Total			57	9,142	8,805	16	456	69%	1982	3.3	12.9	1.2	60.7
TANKER	2	<30,000	237	13,261	10,008	14	132	30%	1984	3.6	14.4	2.1	72.3
TANKER	2	30,000 - 60,000	78	43,461	12,616	15	125	41%	1982	3.4	14.2	2.4	62.8
TANKER	2	60,000 - 90,000	111	77,375	16,026	15	95	0%	1983	3.3	14.9	2.2	70.8
TANKER	2	90,000 - 120,000	91	98,373	15,451	15	97	0%	1991	3.4	13.8	2.4	83.0
TANKER	2	120,000 - 150,000	150	137,083	23,046	15	93	0%	1982	3.4	16.5	3.2	137.4
TANKER	2	> 150,000	32	155,676	25,559	15	85	0%	1983	3.3	16.3	3.2	122.6
TANKER	4	<30,000	57	15,655	7,077	14	413	89%	1981	3.7	14.0	2.0	61.6
TANKER	4	30,000 - 60,000	5	44,153	15,360	15	133	19%	1980	3.3	15.7	2.8	63.9
TANKER	4	60,000 - 90,000	17	80,320	14,305	15	416	75%	1981	3.4	14.7	2.6	77.3
TANKER	ST	<30,000	24	26,755	14,646	16	133	19%	1959	3.1	14.0	2.3	88.4
TANKER	ST	30,000 - 60,000	54	35,574	15,498	16	133	19%	1962	3.1	13.8	2.0	65.8
TANKER	ST	90,000 - 120,000	2	92,760	23,923	16	133	19%	1976	3.1	14.6	2.3	70.2
TANKER	ST	> 150,000	10	276,808	36,324	16	133	19%	1973	3.2	15.4	3.0	104.1
TANKER Total			868	74,084	15,137	15	133	19%	1982	3.4	14.8	2.4	85.1
VEHICLE CARRIER	2	<12,500	39	12,115	11,877	18	117	0%	1982	2.8	7.6	1.2	17.7
VEHICLE CARRIER	2	12,500 - 15,000	5	13,813	12,859	18	111	0%	1986	2.7	10.1	1.3	27.2
VEHICLE CARRIER	2	15,000 - 17,500	7	16,209	13,911	18	111	0%	1984	2.7	9.0	1.0	23.9
VEHICLE CARRIER	2	> 17,500	13	18,558	15,224	19	101	0%	1987	2.7	6.9	1.0	25.2
VEHICLE CARRIER	4	<12,500	8	10,382	13,150	18	527	100%	1977	2.8	13.2	1.4	39.9
VEHICLE CARRIER	4	12,500 - 15,000	1	14,501	14,770	18	143	8%	1983	2.7	9.5	1.0	18.0
VEHICLE CARRIER Total			73	13,678	12,914	18	143	8%	1983	2.7	8.4	1.2	22.7
Grand Total			2,560	38,991	12,476	16	236	0	1984	3.2	13.5	1.8	74.1

Ship Type	Engine Type	DWT Range	Calls	DWT (tonnes)	Power (HP)	Vessel Speed (knots)	Engine Speed (RPM)	%RPM >130	Date of Build	Cruise (hr/call)	RSZ (hr/call)	Maneuver (hr/call)	Hotel (hr/call)
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Table 9-5: Summary of 1996 Deep-Sea Vessel Data for Puget Sound Area Ports Including Seattle, WA

Ship Type - Manip	Stroke type	DWT Range	Calls	DWT (tonnes)	Power (HP)	Vessel Speed (knots)	Engine Speed (RPM)	% RPM >130	Date of Build	Cruise (hr/call)	RSZ (hr/call)	Maneuver (hr/call)	Hotel (hr/call)
BULK CARRIER	2	<25,000	165	22,130	7,073	14	150	94%	1990	3.6	15.4	1.4	70.6
BULK CARRIER	2	25,000 - 35,000	306	27,887	8,155	14	124	32%	1988	3.5	16.5	1.5	128.1
BULK CARRIER	2	35,000 - 45,000	167	40,489	10,752	15	107	3%	1985	3.4	16.3	1.6	88.1
BULK CARRIER	2	> 45,000	216	66,419	12,646	15	98	0%	1987	3.5	15.8	2.0	154.1
BULK CARRIER	4	<25,000	8	6,436	3,625	13	ND	ND	1977	4.0	17.7	5.1	84.4
BULK CARRIER	4	25,000 - 35,000	2	32,019	10,400	15	518	100%	1983	3.5	14.6	1.4	96.8
BULK CARRIER	4	35,000 - 45,000	2	41,642	10,943	14	117	0%	1989	3.6	13.4	0.9	64.3
BULK CARRIER	4	> 45,000	13	63,029	14,806	15	400	100%	1983	3.4	16.6	2.1	177.9
BULK CARRIER	ST	> 45,000	13	82,035	17,111	16	ND	ND	1968	3.1	21.5	1.4	58.8
BULK CARRIER Total			892	39,661	9,727	14	123	34%	1987	3.5	16.2	1.7	115.4
CONTAINER SHIP	2	<25,000	184	19,019	18,365	19	135	77%	1985	2.7	17.9	1.0	34.3
CONTAINER SHIP	2	25,000 - 35,000	135	31,480	26,364	20	101	0%	1984	2.5	16.6	0.9	25.9
CONTAINER SHIP	2	35,000 - 45,000	363	40,261	31,808	22	93	0%	1987	2.3	16.4	1.0	30.9
CONTAINER SHIP	2	> 45,000	276	56,958	51,033	23	95	0%	1992	2.2	16.0	0.9	28.4
CONTAINER SHIP	4	<25,000	8	19,987	12,405	19	428	100%	1988	2.7	16.0	1.1	59.5
CONTAINER SHIP	ST	<25,000	3	19,800	26,797	21	ND	ND	1980	2.4	18.2	1.5	138.7
CONTAINER SHIP	ST	25,000 - 35,000	93	28,628	30,080	20	ND	ND	1973	2.5	16.5	0.9	40.4
CONTAINER SHIP	ST	35,000 - 45,000	64	38,988	31,565	21	ND	ND	1973	2.4	15.5	0.9	17.8
CONTAINER SHIP	ST	> 45,000	24	47,851	80,006	23	ND	ND	1972	2.2	16.2	0.9	30.3
CONTAINER SHIP Total			1,150	38,791	34,337	21	98	5%	1985	2.4	16.5	0.9	30.8
FISHING	2	<1500	12	789	1,897	12	ND	ND	1973	4.3	21.1	5.9	1291.8
FISHING	2	1,500 - 3,000	3	1,883	3,626	14	150	100%	1987	3.5	15.9	1.8	33.4
FISHING	2	3,000 - 4,500	1	4,500	10,768	18	660	100%	1996	2.8	16.7	0.9	1432.0
FISHING	2	> 4,500	2	9,360	10,331	18	ND	ND	1984	2.8	16.0	3.7	654.3
FISHING	4	<1500	20	698	1,702	12	773	100%	1983	4.3	20.1	4.3	915.6
FISHING	4	1,500 - 3,000	10	1,861	5,159	16	720	100%	1978	3.1	13.2	1.8	321.5
FISHING	4	3,000 - 4,500	2	3,372	14,398	15	500	100%	1991	3.3	16.3	7.9	1405.4
FISHING	4	> 4,500	27	5,805	8,048	14	720	100%	1993	3.6	14.8	4.3	399.2
FISHING	ST	> 4,500	4	19,286	37,976	20	ND	ND	1964	2.5	13.0	4.1	534.6
FISHING Total			81	3,846	6,774	14	686	100%	1984	3.7	16.9	4.2	686.4
GENERAL CARGO	2	<15,000	7	3,540	3,647	12	200	100%	1987	4.3	17.9	2.8	65.2
GENERAL CARGO	2	15,000 - 30,000	73	21,745	11,495	16	130	29%	1981	3.1	18.4	1.5	52.4
GENERAL CARGO	2	30,000 - 45,000	52	41,323	12,006	15	104	5%	1984	3.3	13.3	1.0	32.0
GENERAL CARGO	2	> 45,000	77	45,539	10,164	15	98	0%	1988	3.3	16.2	1.1	23.2
GENERAL CARGO	4	<15,000	21	9,063	9,493	15	278	100%	1982	3.5	17.9	2.1	353.6
GENERAL CARGO	4	15,000 - 30,000	32	20,039	20,164	18	ND	ND	1985	2.9	17.6	2.1	112.5
GENERAL CARGO	ST	<15,000	1	14,897	15,289	19	ND	ND	1966	2.6	18.3	0.9	163.9
GENERAL CARGO Total			263	30,851	11,907	16	122	17%	1984	3.2	16.6	1.4	71.9
MISCELLANEOUS	2	(blank)	3	7,900	9,387	14	ND	ND	1991	3.6	19.3	2.4	2189.6
MISCELLANEOUS	2	(blank)	1	1,200	1,860	12	ND	ND	1990	4.2	22.4	0.9	472.8
MISCELLANEOUS	4	(blank)	4	761	3,486	13	1225	100%	1986	3.8	16.1	3.2	300.1
MISCELLANEOUS	ST	(blank)	3	3,988	8,483	15	ND	ND	1940	3.3	15.4	0.9	49.0
MISCELLANEOUS Total			11	3,548	5,827	14	1225	100%	1983	3.7	17.3	2.1	762.6
PASSENGER	2	<5,000	3	4,226	29,370	21	ND	ND	1983	2.4	14.5	1.4	67.1
PASSENGER	2	5,000 - 10,000	1	5,340	32,350	19	ND	ND	1986	2.6	17.5	0.9	7.7
PASSENGER	4	<5,000	4	850	9,906	16	788	100%	1983	3.2	17.1	0.9	9.5
PASSENGER	4	5,000 - 10,000	3	7,089	45,589	21	514	100%	1993	2.4	16.2	0.9	54.6

Table 9-5: Summary of 1996 Deep-Sea Vessel Data for Puget Sound Area Ports Including Seattle, WA

Ship Type - Manip	Stroke type	DWT Range	Calls	DWT (tonnes)	Power (HP)	Vessel Speed (knots)	Engine Speed (RPM)	% RPM >130	Date of Build	Cruise (hr/call)	RSZ (hr/call)	Maneuver (hr/call)	Hotel (hr/call)
PASSENGER	ST	5,000 - 10,000	2	8,706	25,154	23	ND	ND	1958	2.2	17.6	0.9	67.5
PASSENGER Total			13	4,623	26,704	19	670	100%	1982	2.6	16.4	1.0	42.0
REEFER	2	<5,000	17	3,307	4,767	15	155	100%	1986	3.3	15.6	3.9	315.7
REEFER	2	5,000 - 10,000	21	6,642	6,945	17	163	100%	1988	3.0	14.1	3.4	163.2
REEFER	2	10,000 - 15,000	7	11,746	11,969	20	115	0%	1988	2.6	15.6	2.4	201.5
REEFER	4	<5,000	7	2,004	1,730	11	230	100%	1970	4.7	22.1	1.5	259.8
REEFER	4	5,000 - 10,000	8	5,804	5,676	16	634	100%	1991	3.1	16.7	1.0	51.5
REEFER Total			60	5,640	6,136	16	272	88%	1986	3.3	16.0	2.9	207.3
RORO	2	<10,000	11	7,976	6,738	16	174	75%	1988	3.3	22.1	1.3	30.1
RORO	2	10,000 - 20,000	16	11,346	8,004	16	162	81%	1992	3.3	19.9	0.9	24.4
RORO	2	20,000 - 30,000	16	26,787	18,649	19	ND	ND	1983	2.6	17.9	0.9	25.0
RORO	2	> 30,000	4	41,856	15,136	14	ND	ND	1981	3.5	14.2	0.9	10.3
RORO	ST	10,000 - 20,000	121	17,084	29,764	25	ND	ND	1976	2.0	17.0	1.4	73.8
RORO Total			168	17,455	24,777	23	166	79%	1979	2.3	17.6	1.3	60.1
TANKER	2	<30,000	66	19,629	9,104	15	176	79%	1986	3.5	19.0	4.3	43.7
TANKER	2	30,000 - 60,000	79	46,934	12,451	15	107	0%	1984	3.4	15.9	4.0	67.6
TANKER	2	60,000 - 90,000	18	71,315	15,262	15	89	0%	1984	3.3	16.0	3.3	45.2
TANKER	2	90,000 - 120,000	20	100,679	14,738	14	94	0%	1991	3.5	15.8	2.6	64.0
TANKER	2	120,000 - 150,000	26	123,742	26,146	16	ND	ND	1974	3.1	14.5	7.2	63.9
TANKER	4	<30,000	12	10,056	4,864	13	245	33%	1976	4.0	15.6	0.9	16.2
TANKER	4	30,000 - 60,000	1	37,350	11,700	14	520	100%	1981	3.6	17.0	4.2	84.7
TANKER	ST	<30,000	18	19,992	14,795	18	ND	ND	1964	2.8	14.4	3.8	59.7
TANKER	ST	30,000 - 60,000	35	39,541	13,809	16	ND	ND	1969	3.1	15.4	3.5	45.3
TANKER	ST	60,000 - 90,000	125	71,997	19,286	17	ND	ND	1970	3.0	16.6	3.4	62.4
TANKER	ST	90,000 - 120,000	29	91,915	23,095	16	ND	ND	1977	3.2	15.9	5.3	52.1
TANKER	ST	120,000 - 150,000	119	122,732	26,360	16	ND	ND	1974	3.1	14.7	6.2	62.8
TANKER	ST	> 150,000	5	189,978	27,620	14	ND	ND	1978	3.5	11.1	1.9	103.4
TANKER Total			553	73,490	18,099	16	129	22%	1977	3.2	16.0	4.4	58.3
VEHICLES CARRIER	2	<12,500	27	10,286	10,289	17	158	82%	1983	3.0	20.0	0.9	32.2
VEHICLES CARRIER	2	12,500 - 15,000	33	13,709	14,049	18	109	9%	1985	2.7	18.6	1.2	19.0
VEHICLES CARRIER	2	15,000 - 17,500	49	16,272	14,023	18	120	0%	1984	2.8	17.3	1.5	19.6
VEHICLES CARRIER	2	> 17,500	7	19,783	15,501	18	98	0%	1985	2.7	18.4	1.7	19.9
VEHICLES CARRIER	4	<12,500	19	10,981	13,118	18	ND	ND	1981	2.7	20.2	0.9	20.2
VEHICLES CARRIER	4	12,500 - 15,000	4	12,917	13,600	19	ND	ND	1980	2.6	20.2	0.9	13.5
VEHICLES CARRIER	4	15,000 - 17,500	2	17,224	16,880	19	450	100%	1978	2.6	18.9	0.9	22.0
VEHICLES CARRIER	4	> 17,500	1	19,712	16,880	18	ND	ND	1981	2.8	19.4	3.1	21.1
VEHICLES CARRIER Total			142	13,946	13,319	18	137	22%	1984	2.8	18.7	1.2	21.8
Grand Total			3,333	40,347	20,617	18	139	25%	1984	2.9	16.5	1.9	83.9

Table 10-5: Summary of 1996 Deep-Sea Vessel Data for the Port of Corpus Christi, TX

Port of Corpus Christ, TX

SOURCE:

EPA document *Commercial Marine Activity of Deep Sea Ports*, Table 10-5: Summary of 1996 Deep-Sea Vessel Data for the Port of Corpus Christi, TX

Ship Type Manip	Stroke type	DWT Category	DWT Range	Calls	DWT (tonnes)	Power (HP)	Vessel Speed (knots)	Engine Speed (RPM)	%RPM >130	Date of Build	Cruise (hr/call)	RSZ (hr/call)
BARGE CARRIER	ST	2	25,000 - 35,000	2	30,298	31,564	22	ND	ND	1972	2.3	5.0
BARGE CARRIER Total				2	30,298	31,564	22	ND	ND	1972	2.3	5.0
BULK CARRIER	2	1	< 25,000	38	14,322	6,448	13	151	67%	1974	3.9	5.0
BULK CARRIER	2	2	25,000 - 35,000	35	28,117	11,029	15	150	100%	1977	3.3	5.0
BULK CARRIER	2	3	35,000 - 45,000	21	39,326	11,298	15	108	17%	1981	3.3	5.0
BULK CARRIER	2	4	45,000 - 90,000	60	68,076	14,830	15	93	0%	1982	3.4	5.0
BULK CARRIER	2	5	> 90,000	36	133,928	19,693	15	91	0%	1989	3.4	6.6
BULK CARRIER	4	1	< 25,000	5	18,600	8,100	15	ND	ND	1978	3.3	5.0
BULK CARRIER	4	2	25,000 - 35,000	6	29,485	11,036	14	460	100%	1979	3.6	5.0
BULK CARRIER	4	3	35,000 - 45,000	1	36,414	15,600	17	ND	ND	1981	2.9	5.0
BULK CARRIER	4	4	45,000 - 90,000	7	70,656	12,057	14	440	100%	1981	3.6	5.0
BULK CARRIER Total				209	57,708	12,793	15	162	28%	1981	3.5	5.3
CONTAINER SHIP	2	4	> 45,000	1	65,642	66,398	24	100	0%	1996	2.1	5.0
CONTAINER SHIP Total				1	65,642	66,398	24	100	0%	1996	2.1	5.0
TANKER	2	1	<30,000	66	19,231	8,852	15	183	88%	1983	3.4	5.0
TANKER	2	2	30,000 - 60,000	276	44,487	11,085	15	123	44%	1984	3.4	5.0
TANKER	2	3	60,000 - 90,000	161	76,375	15,241	15	99	0%	1984	3.3	5.0
TANKER	2	4	90,000 - 120,000	171	98,320	15,403	15	89	0%	1991	3.4	6.6
TANKER	2	5	120,000 - 150,000	31	139,846	21,270	15	85	0%	1987	3.4	6.6
TANKER	2	6	above 150,000	5	155,042	20,124	14	85	0%	1991	3.5	6.6
TANKER	4	1	<30,000	34	8,311	4,828	14	532	78%	1984	3.7	5.0
TANKER	4	2	30,000 - 60,000	24	43,869	15,369	16	ND	ND	1975	3.2	5.0
TANKER	4	3	60,000 - 90,000	27	77,584	14,563	15	275	50%	1983	3.4	5.0
TANKER	ST	1	<30,000	2	25,943	10,968	16	ND	ND	1954	3.2	5.0
TANKER	ST	2	30,000 - 60,000	522	37,414	13,060	16	ND	ND	1957	3.2	5.0
TANKER	ST	3	60,000 - 90,000	4	63,000	19,727	16	ND	ND	1971	3.1	5.0
TANKER	ST	4	90,000 - 120,000	9	91,898	24,166	16	ND	ND	1977	3.1	6.6
TANKER Total				1,332	53,948	13,178	15	128	24%	1974	3.3	5.3
GENERAL CARGO	2	1	< 25,000	6	9,861	5,483	15	200	100%	1319	3.4	5.0

Table 11-6: Summary of 1996 Deep-Sea Vessel Data for the Port of Tampa, FL

Tampa Harbor, FL

SOURCE:

EPA document *Commercial Marine Activity of Deep Sea Ports*, Table 11-6: Summary of 1996 Deep-Sea Vessel Data for the Port of Tampa, FL

Ship-type	Engine Type	DWT CAT	DWT RANGE	Calls	DWT (tonnes)	Power (HP)	Vessel Speed (knots)	Engine Speed (RPM)	% RPM >130	Date of Build	Cruise (hr/call)	RSZ (hr/call)
BULK CARRIER	2	1	<25,000	52	18,828	8,478	15	158	56%	1979	3.4	5.6
BULK CARRIER	2	2	25,000 - 35,000	82	29,575	9,367	15	125	32%	1983	3.4	5.5
BULK CARRIER	2	3	35,000 - 45,000	66	39,389	10,670	15	114	14%	1983	3.4	5.4
BULK CARRIER	2	4	> 45,000	117	57,952	13,451	15	110	0%	1979	3.4	5.4
BULK CARRIER	4	1	<25,000	8	15,900	6,581	14	124	23%	1975	3.5	5.5
BULK CARRIER	4	2	25,000 - 35,000	2	29,089	8,198	14	157	100%	1995	3.6	5.4
BULK CARRIER	4	3	35,000 - 45,000	1	41,455	11,336	14	117	0%	1995	3.6	5.3
BULK CARRIER	ST	4	> 45,000	1	92,854	10,876	16	124	23%	1975	3.1	5.3
BULK CARRIER	0	0	0	229	39,830	10,876	15	124	23%	1981	3.4	5.4
BULK CARRIER Total				558	39,830	10,876	15	124	23%	1981	3.4	5.4
CONTAINER SHIP	2	3	35,000 - 45,000	2	36,750	23,945	21	259	50%	1986	2.4	5.7
CONTAINER SHIP	2	4	> 45,000	1	60,639	51,920	24	90	0%	1990	2.1	5.3
CONTAINER SHIP	4	1	<25,000	1	21,540	16,993	20	428	100%	1993	2.5	4.4
CONTAINER SHIP Total				4	38,920	29,201	22	259	50%	1989	2.3	5.3
GENERAL CARGO	2	1	<15,000	37	6,769	4,048	14	197	100%	1979	3.7	5.5
GENERAL CARGO	2	2	15,000 - 30,000	22	21,512	9,736	16	130	50%	1982	3.2	5.8
GENERAL CARGO	2	3	30,000 - 45,000	2	34,336	10,300	15	95	0%	1980	3.5	5.7
GENERAL CARGO	2	4	> 45,000	1	46,641	8,950	15	105	0%	1995	3.3	5.3
GENERAL CARGO	4	1	<15,000	70	3,158	2,322	13	554	100%	1978	3.9	5.8
GENERAL CARGO	4	2	15,000 - 30,000	5	19,880	10,120	15	280	86%	1981	3.5	5.9
GENERAL CARGO	ST	1	<15,000	14	14,897	4,428	19	280	86%	1966	2.6	5.4
GENERAL CARGO	0	0	0	191	9,060	4,428	14	280	86%	1978	3.6	5.8
GENERAL CARGO Total				342	9,060	4,428	14	280	86%	1978	3.6	5.8
PASSENGER	2	1	<5,000	26	4,243	29,370	21	559	75%	1984	2.4	6.0
PASSENGER	2	2	5,000 - 10,000	55	6,456	29,961	19	120	0%	1984	2.6	6.0
PASSENGER	4	1	<5,000	5	1,254	9,313	17	769	100%	1979	3.0	6.0
PASSENGER	4	2	5,000 - 10,000	2	5,500	20,934	18	580	100%	1987	2.8	6.0
PASSENGER	0	0	0	32	5,485	28,408	20	559	75%	1984	2.5	6.0
PASSENGER Total				120	5,485	28,408	20	559	75%	1984	2.5	6.0
REEFER	2	2	5,000 - 10,000	46	6,417	8,160	18	158	70%	1986	2.8	4.0

Table 11-6: Summary of 1996 Deep-Sea Vessel Data for the Port of Tampa, FL

Tampa Harbor, FL

REEFER	2	3	10,000 - 15,000	6	11,054	12,983	20	120	0%	1976	2.6	3.5
REEFER	4	1	<5,000	1	3,536	3,002	14	600	100%	1978	3.6	3.5
REEFER	4	2	5,000 - 10,000	1	6,502	6,933	16	168	100%	1995	3.1	3.5
REEFER Total				54	6,880	8,578	18	168	70%	1985	2.8	3.9
RORO	2	1	<5,000	30	872	1,948	14	650	100%	1959	3.6	5.6
RORO	4	1	<5,000	12	2,697	2,849	13	750	100%	1977	3.9	6.0
RORO	4	2	5,000 - 10,000	2	7,440	9,000	15	600	100%	1993	3.3	6.0
RORO Total				44	1,668	2,514	14	650	100%	1966	3.7	5.8
TANKER	2	1	<30,000	111	19,007	11,871	16	136	47%	1978	3.1	5.5
TANKER	2	2	30,000 - 60,000	17	39,778	16,976	17	122	0%	1977	3.0	5.5
TANKER	4	1	<30,000	45	3,121	1,542	11	459	100%	1972	4.5	5.6
TANKER	4	2	30,000 - 60,000	3	37,874	16,000	16	150	44%	1971	3.1	5.4
TANKER	ST	1	<30,000	37	24,854	9,794	14	150	44%	1947	3.5	5.7
TANKER	ST	2	30,000 - 60,000	121	37,075	9,794	15	150	44%	1955	3.3	5.4
TANKER	ST	6	> 150,000	1	228,274	9,794	17	150	44%	1977	2.9	6.0
TANKER	0	0	0	148	25,893	9,794	15	150	44%	1966	3.4	5.4
TANKER Total				483	25,893	9,794	15	150	44%	1966	3.4	5.5
TUG	2	0	0	701	75	4,905	12	ND	ND	1976	4.3	5.4
TUG	4	0	0	166	157	9,206	14	ND	ND	1978	3.7	5.6
TUG	0	0	0	459	91	5,768	13	ND	ND	1976	4.2	5.5
TUG Total				1,326	91	5,768	13	#N/A	#N/A	1976	4.2	5.4
VEHICLES CARRIER	2	2	12,500 - 15,000	2	13,208	11,500	18	111	0%	1984	2.8	5.7
VEHICLES CARRIER Total				2	13,208	11,500	18	111	0%	1984	2.8	5.7
BARGE DRY CARGO	0	0	0	525	ND	ND	ND	ND	ND	ND	ND	5.4
BARGE DRY CARGO Total				525	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	5.4
BARGE TANKER	0	0	0	852	ND	ND	ND	ND	ND	ND	ND	5.5
BARGE TANKER Total				852	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	5.5
MISCELLANEOUS	2	1	<1,000	4	113	895	12	430	100%	1977	4.2	5.9
MISCELLANEOUS	2	3	5,000 - 10,000	1	9,360	10,332	18	430	100%	1984	2.8	3.5

Table 11-6: Summary of 1996 Deep-Sea Vessel Data for the Port of Tampa, FL

Man. (hr/call)	Hotel (hr/call)
1.9	76.2
2.8	87.4
2.7	96.1
3.4	71.9
1.4	346.8
3.3	64.6
3.0	223.2
9.0	265.3
1.5	56.3
2.3	75.6
3.3	276.3
1.0	7.1
3.0	125.9
2.6	171.4
1.8	46.2
1.4	80.8
1.0	43.5
5.7	120.8
1.2	98.7
1.7	51.4
1.2	35.7
1.2	62.3
1.3	68.0
1.1	15.1
1.0	10.2
1.8	224.3
1.0	9.5
1.0	71.8
1.0	36.6
1.0	38.8

Table 11-6: Summary of 1996 Deep-Sea Vessel Data for the Port of Tampa, FL

5.0	352.4
1.0	86.2
1.0	81.8
1.5	75.3
2.0	60.3
1.5	216.1
1.5	199.9
1.9	110.3
1.3	34.3
1.7	37.0
1.4	86.0
1.8	35.9
1.1	21.1
1.9	47.7
2.4	640.7
1.2	21.9
1.4	39.0
2.1	55.7
2.1	64.9
1.6	49.6
1.9	54.7
1.3	203.3
1.3	203.3
1.8	91.8
1.8	91.8
2.0	149.6
2.0	149.6
1.1	83.5
1.0	319.7

Table 12-5: Summary of 1996 Deep-Sea Vessel Data for Baltimore Harbor, MD

Ship Type	Engine Type	DWT Range	Calls	DWT (tonnes)	Power (hp)	Vessel Speed (knots)	Engine Speed (RPM)	%RPM >130	Date of Build	Cruise (hr/call)	RSZ (hr/call)	Maneuver (hr/call)	Hotel (hr/call)
BULK CARRIER	2	< 25,000	50	18,690	8,707	15	146	63%	1981	3.4	16.0	1.5	113.5
BULK CARRIER	2	25,000 - 35,000	85	29,958	10,618	15	131	61%	1982	3.3	16.7	1.5	167.7
BULK CARRIER	2	35,000 - 45,000	73	39,143	10,435	15	109	5%	1984	3.4	16.6	1.6	133.1
BULK CARRIER	2	45,000 - 90,000	144	68,715	13,970	14	100	3%	1986	3.5	17.4	1.5	79.1
BULK CARRIER	2	> 90,000	76	133,223	18,241	14	86	0%	1985	3.5	18.9	1.4	49.5
BULK CARRIER	4	< 25,000	10	12,466	5,700	14	ND	ND	1974	3.7	14.7	1.5	63.6
BULK CARRIER	4	25,000 - 35,000	3	32,322	8,602	13	157	100%	1984	4.0	20.1	1.3	181.8
BULK CARRIER	4	45,000 - 90,000	3	89,127	12,600	14	404	100%	1982	3.6	17.5	1.3	91.0
BULK CARRIER	4	> 90,000	2	158,526	17,850	14	399	100%	1986	3.6	17.2	2.5	64.7
BULK CARRIER	ST	< 25,000	29	18,232	9,115	15	ND	ND	1975	3.3	14.2	1.3	30.3
BULK CARRIER	ST	25,000 - 35,000	1	33,373	11,837	15	ND	ND	1983	3.3	10.7	1.3	1.2
BULK CARRIER	ST	> 90,000	5	159,743	27,126	16	ND	ND	1970	3.1	17.2	1.3	61.4
BULK CARRIER Total			481	59,304	12,611	15	111	16%	1983	3.4	17.0	1.5	98.8
CONTAINER SHIP	2	< 25,000	247	21,107	18,352	19	118	16%	1987	2.6	14.1	1.3	23.7
CONTAINER SHIP	2	25,000 - 35,000	96	29,065	16,979	19	102	0%	1984	2.7	14.5	1.3	17.2
CONTAINER SHIP	2	35,000 - 45,000	92	39,319	46,221	23	105	0%	1979	2.2	16.9	1.4	16.1
CONTAINER SHIP	2	45,000 - 90,000	72	55,730	41,379	22	94	0%	1988	2.2	17.1	1.3	13.7
CONTAINER SHIP	4	< 25,000	13	8,793	6,508	16	475	100%	1984	3.2	13.4	1.3	105.4
CONTAINER SHIP	ST	< 25,000	3	18,832	28,112	23	ND	ND	1973	2.2	14.1	1.3	12.7
CONTAINER SHIP	ST	25,000 - 35,000	18	26,826	35,181	20	ND	ND	1973	2.5	15.5	1.3	20.7
CONTAINER SHIP Total			541	30,106	26,242	20	117	10%	1985	2.5	15.1	1.3	21.7
GENERAL CARGO	2	< 25,000	114	16,545	10,516	16	154	55%	1982	3.1	16.7	1.5	108.3
GENERAL CARGO	2	25,000 - 35,000	13	30,370	10,302	15	108	0%	1984	3.3	16.5	2.0	96.8
GENERAL CARGO	2	35,000 - 45,000	9	41,141	13,058	16	ND	ND	1984	3.1	14.3	1.3	29.8
GENERAL CARGO	2	45,000 - 90,000	1	45,000	12,300	16	93	0%	1994	3.1	17.4	1.3	180.0
GENERAL CARGO	4	< 25,000	80	5,301	3,469	13	642	100%	1988	3.8	19.0	1.4	55.7
GENERAL CARGO	4	25,000 - 35,000	4	29,719	12,000	14	ND	ND	1974	3.6	18.0	2.1	107.2
GENERAL CARGO	ST	< 25,000	5	13,264	16,709	20	ND	ND	1962	2.6	17.4	1.3	358.9
GENERAL CARGO Total			226	14,626	8,281	15	435	78%	1984	3.4	17.4	1.5	91.7
Miscellaneous	2	< 10,000	4	6,450	3,500	15	ND	ND	1982	3.3	15.9	2.0	509.1

Table 12-5: Summary of 1996 Deep-Sea Vessel Data for Baltimore Harbor, MD

Ship Type	Engine Type	DWT Range	Calls	DWT (tonnes)	Power (hp)	Vessel Speed (knots)	Engine Speed (RPM)	%RPM >130	Date of Build	Cruise (hr/call)	RSZ (hr/call)	Maneuver (hr/call)	Hotel (hr/call)
Miscellaneous	4	< 10,000	6	7,053	11,671	14	720	100%	1990	3.5	18.3	1.8	790.1
Miscellaneous Total			10	6,812	10,503	15	720	100%	1987	3.4	17.3	1.9	677.7
PASSENGER	2	<10,000	3	6,291	22,000	20	ND	ND	1976	2.5	15.1	1.3	81.9
PASSENGER	4	<10,000	6	5,478	32,171	20	524	100%	1986	2.6	15.1	1.3	85.7
PASSENGER	ST	<10,000	6	7,942	35,363	24	ND	ND	1961	2.1	16.1	1.3	146.7
PASSENGER Total			15	6,626	31,413	21	524	100%	1974	2.4	15.5	1.3	109.4
REEFER	2	10,000 - 20,000	2	11,560	13,100	19	117	0%	1987	2.6	10.9	1.6	531.4
REEFER Total			2	11,560	13,100	19	117	0%	1987	2.6	10.9	1.6	531.4
RORO	2	<10,000	66	5,420	9,650	16	96	0%	1981	3.1	17.1	1.5	47.8
RORO	2	10,000 - 20,000	46	15,272	14,935	19	98	0%	1985	2.7	15.1	2.0	30.3
RORO	2	20,000 - 30,000	51	26,522	16,952	20	102	0%	1984	2.6	14.6	1.9	32.6
RORO	2	> 30,000	83	45,016	26,562	19	98	0%	1983	2.7	17.4	1.3	19.8
RORO	4	<10,000	3	8,903	10,332	15	425	100%	1979	3.3	15.8	1.3	33.6
RORO	4	20,000 - 30,000	1	24,106	27,000	22	ND	ND	1972	2.3	16.2	1.3	1301.3
RORO Total			250	24,800	17,805	18	107	3%	1983	2.8	16.3	1.6	37.0
TANKER	2	<30,000	53	19,174	8,165	14	157	52%	1984	3.5	15.6	1.6	34.3
TANKER	2	30,000 - 60,000	42	37,543	12,008	15	113	7%	1982	3.3	16.5	1.7	51.5
TANKER	2	60,000 - 90,000	13	64,867	14,170	15	108	0%	1985	3.3	15.9	1.4	34.3
TANKER	2	90,000 - 120,000	1	95,628	16,600	14	94	0%	1993	3.6	17.5	1.3	242.4
TANKER	2	> 150,000	1	281,559	29,460	15	75	0%	1995	3.3	17.2	2.3	93.3
TANKER	4	<30,000	22	8,330	5,354	14	486	100%	1989	3.5	14.5	1.5	29.1
TANKER	4	30,000 - 60,000	7	36,753	14,760	16	ND	ND	1983	3.2	16.8	1.7	39.0
TANKER	ST	30,000 - 60,000	8	44,388	16,275	15	ND	ND	1958	3.3	18.1	1.3	30.9
TANKER Total			147	31,354	10,331	15	222	46%	1983	3.4	15.9	1.6	40.3
TUG	2	<10,000	15	177	4,713	13	900	100%	1975	4.0	16.6	1.3	52.9
TUG	4	<10,000	27	430	15,252	16	750	100%	1978	3.2	14.9	1.4	29.3
TUG Total			42	340	11,488	15	825	100%	1977	3.4	15.5	1.4	37.8
VEHICLES CARRIER	2	<10,000	3	9,352	10,978	18	124	33%	1984	2.8	16.1	2.9	35.4
VEHICLES CARRIER	2	10,000 - 20,000	225	14,660	13,308	18	110	0%	1985	2.7	14.7	1.8	22.8
VEHICLES CARRIER	2	20,000 - 30,000	3	26,342	13,963	19	101	0%	1990	2.7	17.0	1.7	17.0
VEHICLES CARRIER	4	<10,000	12	8,246	11,830	18	530	100%	1980	2.8	14.2	1.5	21.7
VEHICLES CARRIER	4	10,000 - 20,000	50	12,863	13,649	18	502	100%	1981	2.8	15.5	1.9	28.1
VEHICLES CARRIER Total			293	14,156	13,289	18	173	17%	1984	2.7	14.9	1.8	23.7
Grand Total			2,007	31,529	16,493	17	172	23%	1984	3.0	16.0	1.5	56.4

Table 13-5: Summary of 1996 Deep-Sea Vessel Data for the Port of Coos Bay, OR

Ship-type	Engine Type	DWT Range	Calls	DWT (tonnes)	Power (HP)	Vessel Speed (knots)	Engine Speed (RPM)	%RPM >130	Date of Build	Cruise (hr/call)	RSZ (hr/call)	Maneuver (hr/call)	Hotel (hr/call)
BULK CARRIER	2	< 25,000	26	22,978	7,007	14	149	96%	1993	3.6	3.6	0.6	64.0
BULK CARRIER	2	25,000 - 35,000	39	30,108	9,756	15	127	13%	1983	3.4	3.4	0.6	69.4
BULK CARRIER	2	35,000 - 45,000	60	42,436	9,136	14	105	6%	1987	3.5	3.0	0.6	58.9
BULK CARRIER	2	> 45,000	28	46,825	10,249	14	106	0%	1990	3.5	3.5	0.6	94.8
BULK CARRIER	2	(blank)	2	36,790	9,136	14	117	24%	1987	3.5	4.0	0.3	179.7
BULK CARRIER Total			155	36,790	9,136	14	117	24%	1987	3	3.3	0.6	70.4
GENERAL CARGO	2	< 25,000	10	20,800	11,770	16	103	0%	1980	3.1	3.6	0.6	65.3
GENERAL CARGO	2	25,000 - 35,000	18	30,068	8,040	14	95	0%	1984	3.5	3.6	0.6	52.5
GENERAL CARGO	2	35,000 - 45,000	20	42,857	13,010	15	119	0%	1982	3.2	2.7	0.6	56.5
GENERAL CARGO	2	> 45,000	5	46,547	12,300	16	93	0%	1994	3.1	4.0	0.6	128.5
GENERAL CARGO	4	< 25,000	1	23,168	7,800	15	103	0%	1978	3.3	3.0	0.6	67.4
GENERAL CARGO Total			54	34,486	10,962	15	103	0%	1983	3	3.3	0.6	63.7
MISCELLANEOUS	4	(blank)	1	36,189	9,612	15	ND	ND	ND	3.4	4.0	0.3	128.7
MISCELLANEOUS Total			1	#N/A	#N/A	15	#N/A	#N/A	#N/A	#N/A	4.0	0.3	128.7
Grand Total			210	36,189	9,612	15	116	21%	1986	3	3.3	0.6	69.0

Cleveland Harbor, OH

SOURCE:

EPA document *Commercial Marine Activity for Lake and Riv*

Ship Type	Engine Type	DWT Category	Trips	Year Build	DWT (tonnes)
BULK CARRIER, SALTY	2	< 10,000	2	ND	8,186
BULK CARRIER, SALTY	2	10,000 - 20,000	23	ND	15,866
BULK CARRIER, SALTY	2	20,000 - 30,000	134	1984	27,225
BULK CARRIER, SALTY	2	> 30,000	60	1981	35,125
BULK CARRIER, SALTY Total			219	1983	28,022
BULK CARRIER, LAKER	2	10,000 - 20,000	39	1943	17,500
BULK CARRIER, LAKER	2	20,000 - 30,000	717	1977	26,830
BULK CARRIER, LAKER	2	30,000 - 40,000	55	1974	37,107
BULK CARRIER, LAKER	2	> 40,000	37	1980	50,800
BULK CARRIER, LAKER	4	< 10,000	56	1959	7,686
BULK CARRIER, LAKER	4	10,000 - 20,000	350	1951	17,000
BULK CARRIER, LAKER	4	20,000 - 30,000	70	1973	21,303
BULK CARRIER, LAKER	4	30,000 - 40,000	16	1980	33,205
BULK CARRIER, LAKER	ST	10,000 - 20,000	106	1943	15,047
BULK CARRIER, LAKER Total			1446	1967	23,445
CONTAINER SHIP, SALTY	2	< 10,000	4	ND	8,229
CONTAINER SHIP, SALTY	4	10,000 - 20,000	2	1995	10,187
CONTAINER SHIP, SALTY Total			6	1995	8,882
EXCURSION VESSEL	4	450	572	1981	ND
EXCURSION VESSEL	4	1000	748	1990	ND
EXCURSION VESSEL Total			1320	1986	ND
GENERAL CARGO, SALTY	2	< 10,000	2	ND	7,805
GENERAL CARGO, SALTY	2	10,000 - 20,000	6	1980	15,658
GENERAL CARGO, SALTY	4	< 10,000	8	1963	7,251
GENERAL CARGO, SALTY	4	10,000 - 20,000	2	ND	17,154
GENERAL CARGO, SALTY	4	20,000 - 30,000	2	ND	23,000
GENERAL CARGO, SALTY Total			20	1972	12,394
TANKER, SALTY	2	< 10,000	5	1974	8,000
TANKER, SALTY	4	10,000 - 20,000	12	1978	11,420
TANKER, SALTY Total			17	1976	10,280
Grand Total			1665	1968	23,678

a ST refers to steam turbine

b Category is dead weight tonnes for all ship-types

c Hotelling times are found in Table 3-7

Table 3-7. Average hotelling times by ship-type for calls on Port of Cleveland in 1996

Ship-type	Category a Calls		Hotelling (hrs/call)
BULK CARRIER, SALTY	10,000 - 20,000	11	41.3
	20,000 - 30,000	75	69.3
	> 30,000	45	49.1
BULK CARRIER, SALTY Total		131	60
BULK CARRIER, LAKER	20,000 - 30,000	1	7.8
	> 30,000	1	7
BULK CARRIER, LAKER Total		2	7.4
CONTAINER SHIP, SALTY	< 10,000	1	24.7
	10,000 - 20,000	1	111.5
CONTAINER SHIP, SALTY Total		2	68.1
GENERAL CARGO, SALTY	< 10,000	9	55.1
	10,000 - 20,000	6	78.9
GENERAL CARGO, SALTY Total		15	64.6
PASSENGER, SALTY	all	2	30.5
TANKER, SALTY	all	1	29
Grand Total		153	59.3

er Ports, Table 3-4. Summary of trips for the Port of Cleveland for 1996

EMISSION FAC

Cruise
g/hp-hr
2
4
Steam

Power (hp)	Vessel Speed (knots)	Engine Speed (RPM)	Cruise (hr/trip)	RSZ (hr/trip)	Maneuver (hr/trip)	Calls	Hotel (hr/call)	
6,200	14	ND	0.5	0.3	0.8			
6,996	14	113	0.5	0.3	0.8	11	41.3	
9,116	15	110	0.5	0.3	0.8	75	69.3	
10,909	14	100	0.5	0.3	0.8	45	49.1	
9,358	14	109	0.5	0.3	0.8			
4,500	13	ND	0.5	0.3	0.8			
7,098	13	750	0.5	0.3	2.4	0.911055	7.8	
7,087	13	ND	0.5	0.4	1	0.774648	7	
8,538	13	ND	0.5	0.3	0.9			
4,303	14	ND	0.5	0.3	0.9			
4,236	13	ND	0.5	0.3	2			
5,503	14	ND	0.5	0.3	2.5	0.088945	7.8	
9,601	12	ND	0.6	0.4	0.8	0.225352	7	
8,269	15	ND	0.5	0.3	0.9			
6,308	13	750	0.5	0.3	2			
5,950	15	ND	0.5	0.3	0.8	1	24.7	
7,382	16	500	0.4	0.3	0.8	1	111.5	
6,427	15	500	0.5	0.3	0.8			
460	10	ND	0	2	0.4	0.866667	30.5	
850	12	ND	0	2	0.4	1.133333	30.5	
655	11	ND	0	2	0.4			
5,400	15	225	0.5	0.3	0.8	1.8	55.1	
10,600	16	ND	0.4	0.3	0.8	4.5	78.9	
3,391	12	550	0.6	0.4	0.8	7.2	55.1	
6,000	14	ND	0.5	0.3	0.8	1.5	78.9	
7,800	13	ND	0.5	0.4	0.8			
6,456	14	442	0.5	0.3	0.8			
2,950	12	750	0.5	0.3	2.6	0.294118	29	
6,253	15	117	0.5	0.3	0.8	0.705882	29	
5,152	14	328	0.5	0.3	1.4			
6,664	13	519	0.5	0.3	1.8			Total Grams per Year
								2-stroke Tons per Year
								4-stroke Tons per Year

Steam Engine Tons per Year
Total Tons per Year

Load	0.8						RSZ		
HC	CO	NOx	PM	SO2		g/hp-hr	HC		
	0.395	0.82	17.6	1.29	9.56		2	0.395	
	0.395	0.52	12.38	1.31	9.69		4	0.395	
	0.05	0.22	2.09	1.86	15.0	Steam		0.05	
						Speed		9	

Cruise HC g/yr	Cruise CO g/yr	Cruise NOx g/yr	Cruise PM g/yr	Cruise SO2 g/yr	RSZ Load	RSZ HC g/yr
1959	4067	87296	6398	47411		420
25423	52778	1132792	83029	615231		5453
193004	400666	8599670	630317	4670571		41395
103417	214689	4607962	337743	2502632		22181
323804	672201	14427720	1057486	7835845	0.29	69449
27729	57564	1235520	90558	671024		6910
804104	1669279	35828433	2626061	19458796		200386
61586	127849	2744086	201129	1490342		20463
49913	103617	2223978	163007	1207866		12439
38073	50121	1193274	126267	933784		9488
234251	308381	7341835	776882	5745277		58376
60863	80124	1907560	201850	1492741		15167
29126	38343	912848	96594	714339		8065
17530	77133	732064	652126	5245200		4369
1323175.00	2512411.51	54119598.15	4934475.64	36959369.04	0.33	335662.07
3760	7806	167552	12281	90999		708
1866	2457	58489	6189	45770		439
5627	10263	226041	18470	136769	0.25	1148
0	0	0	0	0		100481
0	0	0	0	0		242801
0	0	0	0	0	0.48	343282
1706	3542	76032	5573	41294		366
8039	16689	358195	26254	194540		2155
5143	6771	161205	17058	126150		1226
1896	2496	59424	6288	46502		407
2465	3245	77251	8174	60452		705
19250	32743	732108	63347	468937	0.29	4858
2331	4838	103840	7611	56397		500
11856	15607	371578	39319	290775		2543
14186	20445	475418	46930	347171	0.29	3043
1686041.41	3248063.69	69980884.99	6120709.01	45748091.69		757441.67
1.41	2.93	62.88	4.61	34.15		0.34
0.42	0.56	13.29	1.41	10.40		0.48

0.02	0.08	0.81	0.72	5.77		0.00
1.85	3.57	76.98	6.73	50.32		0.83

CO	NOx	PM	SO2	Maneuver g/hp-hr	HC
	0.82	17.6	1.29	9.56	2 2.085717156
	0.52	12.38	1.31	9.69	4 2.172732372
	0.22	2.09	1.86	15.0	Steam 0.05
knots				Speed	4

EMISSION

RSZ CO g/yr	RSZ NOx g/yr	RSZ PM g/yr	RSZ SO2 g/yr	Maneuvering Load	Maneuvering HC g/yr
872	18723	1372	10169		2407
11320	242958	17808	131953		31232
85934	1844432	135188	1001730		237101
46046	988302	72438	536757		127046
144172	3094415	226807	1680609	0.12	397786
14345	307896	22567	167221		35255
415990	8928569	654424	4849199		3067026
42481	911781	66829	495198		97876
25822	554223	40622	301004		71392
12490	297368	31466	232702		56729
76850	1829611	193602	1431743		775632
19967	475371	50302	371996		251907
10617	252761	26746	197795		32146
19222	182433	162512	1307122		4749
637783.49	13740012.44	1249070.36	9353981.62	0.12	4392711.14
1471	31567	2314	17144		4498
579	13774	1458	10779		2907
2049	45341	3771	27923	0.11	7405
132279	3149253	333241	2464415		30565
319637	7609816	805239	5954982		73856
451916	10759069	1138480	8419397	0.13	104420
760	16307	1195	8857		2096
4474	96031	7039	52155		12345
1614	38417	4065	30062		5485
535	12745	1349	9974		2426
928	22091	2338	17287		3154
8311	185591	15985	118335	0.12	25507
1038	22271	1632	12096		9305
3347	79695	8433	62364		15172
4385	101966	10065	74460	0.12	24477
1248615.90	27926394.13	2644178.51	19674706.43		4952306.03
0.72	15.36	1.13	8.34		4.07
0.64	15.16	1.60	11.86		1.37

0.02	0.20	0.18	1.44		0.01
1.37	30.72	2.91	21.64		5.45

CO	NOx	PM	SO2	Hotel g/hp-hr	Load HC
6.072740558	23.91129555	2.168336646	23.02		2 0.1
4.432346073	16.87604551	2.216072174	23.87		4 0.1
0.22	2.09	1.86	15.0	Steam	0.05

knots

VS ESTIMATES

Maneuvering CO g/yr	Maneuvering NOx g/yr	Maneuvering PM g/yr	Maneuvering SO2 g/yr		Hotelling HC g/yr
7008	27593	2502	26564		
90935	358055	32469	344701		31783
690339	2718197	246493	2616820		473804
369905	1456492	132078	1402171		241034
1158187	4560337	413543	4390255		746621
102647	404172	36651	389098		
8929903	35161316	3188517	33849944		504
284974	1122080	101753	1080231		384
207865	818463	74220	787938		
115726	440624	57860	623168		
1582280	6024490	791104	8520351		
513886	1956608	256931	2767203		38
65578	249685	32787	353126		151
20894	198302	176648	1420824		
11823752.51	46375740.40	4716472.97	49791883.47		1078.33
13097	51570	4677	49647		1470
5930	22579	2965	31932		8231
19027	74149	7641	81580		9701
62351	237401	31174	335753		122
150665	573653	75329	811309		294
213016	811054	106503	1147062		415
6103	24032	2179	23136		5356
35943	141524	12834	136245		37635
11190	42605	5595	60255		13453
4950	18846	2475	26654		7101
6435	24500	3217	34650		
64620	251507	26300	280940		63545
27091	106671	9673	102693		252
30951	117844	15475	166666		1280
58042	224516	25148	269359		1532
13336645.03	52297301.95	5295608.01	55961078.44		822892.04
11.84	46.63	4.23	44.89		0.87
2.80	10.68	1.40	15.10		0.03

0.02	0.22	0.19	1.56		0.00
14.67	57.53	5.83	61.56		0.91

	0.1					All modes
CO	NOx	PM	SO2			
	1.85	9.96	0.239	1.07		
	1.85	9.96	0.239	1.07		
	0.22	2.09	1.86	15.00		

Hotelling CO g/yr	Hotelling NOx g/yr	Hotelling PM g/yr	Hotelling SO2 g/yr	All Modes HC g/yr	All Modes CO g/yr	All Modes NOx g/yr
				4786.24	11947.22	133611.65
587982	3165570	75961	339316	93891.19	743014.79	4899374.74
8765376	47190888	1132392	5058377	945303.92	9942315.34	60353187.19
4459136	24007022	576072	2573305	493678.13	5089775.13	31059777.19
13812494	74363480	1784425	7970999	1537659.47	15787052.48	96445950.77
				69893.95	174556.43	1947587.50
9331	50238	1206	5385	4072019.70	11024503.77	79968556.07
7109	38276	918	4103	180309.58	462413.80	4816223.36
				133743.98	337303.62	3596664.42
				104289.67	178337.82	1931265.47
				1068259.14	1967510.12	15195936.08
706	3803	91	408	327975.20	614683.15	4343341.21
2802	15085	362	1617	69487.81	117338.83	1430378.44
				26647.50	117249.01	1112799.67
19949.03	107401.25	2577.20	11512.31	6052626.54	14993896.54	114342752.23
27189	146377	3512	15690	10436.86	49562.96	397066.35
152272	819801	19672	87874	13443.49	161237.54	914642.37
179461	966178	23184	103564	23880.34	210800.51	1311708.72
2249	12111	291	1298	131167.14	196879.55	3398764.27
5436	29264	702	3137	316950.70	475737.37	8212733.07
7685	41375	993	4435	448117.85	672616.92	11611497.34
99081	533430	12800	57178	9524.38	109486.46	649801.15
696253	3748476	89948	401798	60174.30	753358.55	4344225.53
248876	1339896	32152	143623	25307.18	268450.85	1582123.02
131369	707260	16971	75811	11830.01	139349.59	798274.75
				6323.93	10607.39	123842.56
1175579	6329062	151872	678410	113159.80	1281252.84	7498267.01
4655	25061	601	2686	12386.60	37621.81	257843.63
23680	127491	3059	13666	30850.55	73586.23	696608.31
28335	152552	3661	16352	43237.15	111208.04	954451.94
15223502.69	81960046.94	1966711.97	8785272.74	8218681.15	33056827.31	232164628.01
16.12	86.80	2.08	9.30	6.69	31.61	211.67
0.62	3.36	0.08	0.36	2.32	4.62	42.49

0.00	0.00	0.00	0.00	0.03	0.13	1.22
16.75	90.16	2.16	9.66	9.04	36.36	255.38

8.55 35.62 242.61

All Modes PM g/yr	All Modes SO2 g/yr
10272.88	84143.59
209266.51	1431201.65
2144389.96	13347497.64
1118331.15	7014865.42
3482260.51	21877708.30
149776.67	1227343.00
6470207.21	58163324.86
370629.99	3069873.75
277849.83	2296808.00
215593.86	1789654.26
1761588.06	15697370.60
509174.35	4632348.27
156489.14	1266878.00
991287.07	7973145.70
10902596.17	96116746.44
22783.50	173480.67
30283.41	176355.49
53066.91	349836.16
364705.62	2801465.77
881270.27	6769428.15
1245975.89	9570893.92
21747.52	130464.52
136074.79	784738.29
58869.91	360090.35
27082.79	158939.83
13729.22	112389.42
257504.23	1546622.40
19517.97	173871.48
66285.82	533470.61
85803.79	707342.09
16027207.49	130169149.31
12.05	96.69
4.49	37.73

1.09	8.77
17.63	143.19

16.26

132.66

Burns Waterway Harbor, IN

SOURCE:

EPA document *Commercial Marine Activity for Lake and River Ports*, Table 3-12. Summary of trips for Burns Waterway Harbor for 1996

Ship Type	Engine Type	DWT Category	Trips	Year Build	DWT (tonnes)	Power (hp)	Vessel Speed (knots)	Engine Speed (RPM g/yr)	Cruise (hr/trip)	RSZ (hr/trip)	Maneuver (hr/trip)	Calls
BULK CARRIER, LAKER	2	20,000 - 30,000	9	1973	24,827	8,531	13	750	0.5	0.4	0.7	2.423077
BULK CARRIER, LAKER	2	30,000 - 40,000	37	1974	34,925	7,108	13	ND	0.5	0.4	0.6	1.146018
BULK CARRIER, LAKER	2	> 40,000	162	1975	67,695	14,376	14	ND	0.5	0.3	0.6	5.017699
BULK CARRIER, LAKER	4	10,000 - 20,000	14	1952	17,978	4,800	13	ND	0.5	0.4	0.7	7
BULK CARRIER, LAKER	4	20,000 - 30,000	6	1971	22,491	6,600	15	ND	0.5	0.3	0.7	1.615385
BULK CARRIER, LAKER	4	30,000 - 40,000	27	1979	32,908	9,541	12	ND	0.6	0.4	0.7	0.836283
BULK CARRIER, LAKER	ST	20,000 - 30,000	11	1953	23,627	8,886	16	ND	0.4	0.3	0.6	2.961538
BULK CARRIER, LAKER Total			266	1973	52,630	11,753	14	750	0.5	0.3	0.6	
BULK CARRIER, SALTY	2	10,000 - 20,000	4	1976	14,631	6,700	14	ND	0.5	0.3	0.7	4
BULK CARRIER, SALTY	2	20,000 - 30,000	99	1973	27,329	8,839	13	219	0.5	0.3	0.7	35.77311
BULK CARRIER, SALTY	2	30,000 - 40,000	42	1982	32,449	10,132	14	105	0.5	0.3	0.7	19
BULK CARRIER, SALTY	ST	20,000 - 30,000	20	1961	26,175	3,551	16	ND	0.4	0.3	0.7	7.226891
BULK CARRIER, SALTY Total			165	1974	28,185	8,476	14	193	0.5	0.3	0.7	
GENERAL CARGO, SALTY	2	< 10,000	8	1962	8,395	4,100	14	ND	0.5	0.3	0.7	5.714286
GENERAL CARGO, SALTY	2	10,000 - 20,000	1	1982	16,467	11,200	16	150	0.4	0.3	0.7	1
GENERAL CARGO, SALTY	4	< 10,000	6	1979	5,785	3,667	12	ND	0.6	0.4	0.7	4.285714
GENERAL CARGO, SALTY Total			15	1970	7,889	4,400	13	150	0.5	0.3	0.7	
TANKER, SALTY	4	< 10,000	200	1973	7,500	400	14	720	0.5	0.3	0.6	
TANKER, SALTY Total		< 10,000	200	1973	7500	400	14	720	0.5	0.3	0.6	
Grand Total			646	1973	40,342	9,792	14	596	0.5	0.3	0.7	

a ST refers to steam turbine

b Category is dead weight tonnes for all ship-types

c Hotelling times are found in Table 3-15

Table 3-15. Average hotelling times by ship-type for calls on Burns Waterway Harbor

Ship-type	Category a	Calls	Hotelling (hrs/call)
BULK CARRIER, LAKER	10,000 - 20,000	7	13.5
	20,000 - 30,000	7	17.9
	> 30,000	7	18.7
BULK CARRIER, LAKER Total		21	16.6
BULK CARRIER, SALTY	10,000 - 20,000	4	61
	20,000 - 30,000	43	43.2
	> 30,000	19	48
BULK CARRIER, SALTY Total		66	45.8
GENERAL CARGO, SALTY	< 10,000	10	26.3
	20,000 - 30,000	1	23.9
GENERAL CARGO Total		11	26
DRY-CARGO BARGE	< 2000	446	46.8
LIQUID CARGO BARGE	< 2000	23	52.9
	2000 - 5000	27	29.7
LIQUID CARGO BARGE Total		50	40.3
Grand Total		594	44.4

a Category is in dead weight tonnes.

EMISSION FAC

Cruise	Load	0.8					RSZ						Maneuver		
g/hp-hr	HC	CO	NOx	PM	SO2	g/hp-hr	HC	CO	NOx	PM	SO2	g/hp-hr	HC		
	2	0.395	0.82	17.6	1.29	9.56	2	0.395	0.82	17.6	1.29	9.56	2	2.085717156	
	4	0.395	0.52	12.38	1.31	9.69	4	0.395	0.52	12.38	1.31	9.69	4	2.172732372	
Steam		0.05	0.22	2.09	1.86	15.0	Steam		0.05	0.22	2.09	1.86	15.0	0.05	
							Speed	9 knots					Speed	4	

Hotel (hr/call)	Cruise HC g/yr	Cruise CO g/yr	Cruise NOx g/yr	Cruise PM g/yr	Cruise SO2 g/yr	RSZ Load	RSZ HC g/yr	RSZ CO g/yr	RSZ NOx g/yr	RSZ PM g/yr	RSZ SO2 g/yr	Maneuvering Load	Maneuvering HC g/yr
17.9	12131	25184	540524	39618	293564		3469	7202	154573	11330	83950		13040
18.7	41553	86263	1851492	135706	1005565		11883	24668	529470	38808	287561		38286
18.7	367968	763883	16395540	1201719	8904589		78921	163835	3516467	257741	1909830		339030
13.5	10618	13978	332774	35213	260409		3036	3997	95163	10070	74469		11889
17.9	6257	8237	196099	20750	153455		1342	1767	42059	4450	32913		7006
18.7	48842	64299	1530804	161983	1197915		11639	15323	364803	38602	285472		45576
17.9	1564	6881	65310	58178	467942		419	1845	17509	15597	125454		341
	488933	968724	20912544	1653167	12283440	0.29	110710	218637	4720044	376598	2799649	0.12	455169
61	4234	8790	188672	13829	102470		908	1885	40466	2966	21977		4552
43.2	138260	287020	6160429	451531	3345794		29654	61559	1321271	96843	717596		148618
48	67236	139578	2995830	219581	1627066		14421	29936	642537	47095	348968		72273
43.2	1136	5000	47453	42271	339996		305	1340	12722	11333	91152		289
	210866	440389	9392384	727212	5415326	0.29	45287	94721	2016995	158237	1179693	0.12	225732
26.3	5182	10758	230912	16925	125411		1291	2681	57544	4218	31253		5765
23.9	1416	2939	63078	4623	34259		441	915	19649	1440	10672		1969
26.3	4172	5492	130745	13835	102313		1155	1521	36202	3831	28330		4029
	10770	19189	424735	35383	261982	0.33	2888	5117	113396	9489	70254	0.12	11763
	12640	16640	396160	41920	310011		2711	3569	84967	8991	66490		12132
	12640	16640	396160	41920	310011	0.29	2711	3569	84967	8991	66490	0.12	12132
Total Grams per Year	723209	1444941	31125823	2457682	18270759		161595	322044	6935402	553314	4116087		704795
2-stroke Tons per Year	0.70	1.46	31.27	2.29	16.98		0.16	0.32	6.91	0.51	3.75		0.69
4-stroke Tons per Year	0.09	0.12	2.85	0.30	2.23		0.02	0.03	0.69	0.07	0.54		0.09
Steam Engine Tons per Year	0.00	0.01	0.12	0.11	0.89		0.00	0.00	0.03	0.03	0.24		0.00
Total Tons per Year	0.80	1.59	34.24	2.70	20.10		0.18	0.35	7.63	0.61	4.53		0.78

CO	NOx	PM	SO2	Hotel g/hp-hr	Load HC	CO	NOx	PM	SO2	All modes
6.072740558	23.91129555	2.168336646	23.02		2	0.1	1.85	9.96	0.239	1.07
4.432346073	16.87604551	2.216072174	23.87		4	0.1	1.85	9.96	0.239	1.07
0.22	2.09	1.86	15.0	Steam		0.05	0.22	2.09	1.86	15.00
knots										

EMISSIONS ESTIMATES

Maneuvering CO g/yr	Maneuvering NOx g/yr	Maneuvering PM g/yr	Maneuvering SO2 g/yr		Hotelling HC g/yr	Hotelling CO g/yr	Hotelling NOx g/yr	Hotelling PM g/yr	Hotelling SO2 g/yr	All Modes HC g/yr	All Modes CO g/yr
37967	149494	13556	143918		3700	68453	368536	8843	39503	32340	138805
111472	438917	39802	422547		1523	28181	151719	3641	16263	93245	250583
987115	3886746	352460	3741787		13489	249549	1343518	32239	144011	799408	2164383
24254	92346	12126	130603		4536	83916	451786	10841	48427	30079	126145
14292	54418	7146	76963		1908	35306	190078	4561	20374	16513	59602
92975	354002	46486	500659		1492	27603	148610	3566	15929	107550	200200
1501	14245	12689	102064		2355	10363	98357	87617	706591	4680	20590
1269576	4990167	484266	5118541		29004	503371	2752604	151309	991099	1083816	2960308
13252	52181	4732	50235		16348	302438	1628261	39072	174533	26042	326366
432713	1703799	154505	1640254		136598	2527059	13605137	326469	1458330	453129	3308351
210429	828561	75136	797659		92404	1709471	9203422	220845	986512	246333	2089415
1272	12075	10756	86517		5543	24390	231482	206205	1662942	7273	32002
657667	2596616	245129	2574665		250893	4563357	24668301	792590	4282318	732778	5756134
16786	66095	5994	63630		6162	113992	613707	14726	65783	18401	144217
5732	22569	2047	21727		2677	49521	266609	6398	28578	6502	59107
8218	31292	4109	44255		4133	76465	411670	9878	44127	13489	91696
30737	119956	12149	129613		12972	239977	1291986	31002	138488	38392	295020
24749	94230	12374	133269							27483	44958
24749	94230	12374	133269		0	0	0	0	0	27483	44958
1982728	7800969	753918	7956087		292869	5306706	28712892	974901	5411904	1882468	9056420
2.00	7.86	0.71	7.57		0.30	5.55	29.90	0.72	3.20	1.84	9.33
0.18	0.69	0.09	0.97		0.01	0.25	1.32	0.03	0.14	0.21	0.57
0.00	0.03	0.03	0.21		0.01	0.04	0.36	0.32	2.61	0.01	0.06
2.18	8.58	0.83	8.75		0.32	5.84	31.58	1.07	5.95	2.07	9.96

All Modes NOx g/yr	All Modes PM g/yr	All Modes SO2 g/yr
1213127	73347	560936
2971598	217956	1731935
25142272	1844159	14700218
972069	68250	513908
482654	36908	283705
2398218	250637	1999976
195422	174083	1402050
33375359	2665340	21192728
1909580	60598	349215
22790635	1029348	7161974
13670350	562657	3760206
303731	270565	2180607
38674296	1923168	13452002
968258	41863	286077
371906	14508	95235
609908	31653	219025
1950073	88024	600337
575358	63285	509770
575358	63285	509770
74575086	4739816	35754836
75.94	4.23	31.51
5.54	0.50	3.88
0.55	0.49	3.94
82.03	5.21	39.33

APPENDIX B

Texas Ports Example Calculations

Matched Texas Port Example

From the draft Task 2 report, Beaumont was associated with the Port of Corpus Christi and the ports in Port Arthur, Matagorda, and Brownsville were associated with the Port of Tampa based on the similar vessel drafts of ships for Gulf Coast ports. Table B-1 shows the 1995 vessel trips by vessel type reported by Arcadis (1999). Tables B-2a and 2b show the 1996 and 1999 vessel trips by type of vessel for the detailed ports (Corpus Christi and Tampa) and the 1999 trips for the matched Texas ports with the total trips by vessel with Category 3 engines summed. Although the 1996 and 1999 vessel trips for these ports does not appear extraordinary, other ports show extraordinary differences between the 1995 and 1996 and 1999 vessel trip data.

Table B-1. 1995 Vessel trips for matched ports (Arcadis, 1999).

PORTNAME	BA	BC	BD	BL	CS	GC	OT	PA	RF	RO	SV	TA	TUG	UC	VC	Cat. 3 Total
Corpus Christi, TX	2	407	1,030	7,590	7	27	-	125	-	10	2,702	1,921	4,716	98	-	2,594
Tampa, FL	-	958	1,134	1,312	32	229	17	96	238	64	-	974	2,369	534	2	3,144
Beaumont, TX	-	78	1,846	7,837	6	13	-	2	2	24	357	719	7,268	49	-	892
Port Arthur, TX	-	321	1,398	4,202	24	126	20	10	2	16	95	1,220	5,430	189	-	1,929
Matagorda Ship Channel, TX	-	205	1,435	1,412	2	34	1	-	-	-	6	173	1,265	51	-	466
Brownsville, TX	-	120	330	507	30	25	8	2	-	6	6	88	509	617	2	898

Table B-2a. 1996 Vessel trips for detailed ports (USACE, 2001).

PORTNAME	BA	BC	BD	BL	CS	GC	OT	PA	RF	RO	SV	TA	TUG	UC	VC	Cat. 3 Total
Corpus Christi, TX	6	592	1,392	10,255	10	39	4	182	-	14	3,933	2,142	14,245	142	-	3,126
Tampa, FL	-	1,588	1,370	1,584	53	380	40	160	394	106	-	1,015	3,308	884	4	4,624

Table B-2b. 1999 Vessel trips for matched ports (USACE, 2001).

PORTNAME	BA	BC	BD	BL	CS	GC	OT	PA	RF	RO	SV	TA	TUG	UC	VC	Cat. 3 Total
Corpus Christi, TX	6	707	1,396	10,284	12	47	1	217	-	17	4,693	1,992	13,940	169	-	3,162
Beaumont, TX	-	45	2,035	8,641	3	7	1	1	1	14	205	2,186	10,387	28	-	2,287
Port Arthur, TX	-	369	1,616	4,856	28	145	21	12	2	19	109	266	4,736	218	-	1,079
Matagorda Ship Channel, TX	-	292	1,453	1,429	3	48	2	-	-	-	9	267	1,319	73	-	685
Brownsville, TX	-	50	485	744	13	10	2	1	-	3	3	77	669	259	1	415

BA = Barge Carrier

BC = Bulk Cargo Carrier

BD = Dry-cargo Barge

BL = Liquid Cargo (Tanker) Barge

CS = Container Ship

GC = General Cargo

OT = Other, Unknown, or Undefined

PA = Passenger, Cruise and Excursion

RF = Reefer

RO = RORO and Ferry

SV = Supply Vessel and Support Vessel

TA = Tanker

TUG = Tugboat and Pushboat

UC = Unidentified Dry-cargo

VC = Vehicle Carrier

Arcadis (1999) recommended that unclassified (UC) vessels be reclassified according to the proportion of dry cargo vessels (i.e. all those Category 3 vessels other than tankers (TA) at the port of interest. This procedure was followed for the detailed and matched port trip totals with the result shown in Tables B-3 and B-4. Based on a review of the engines of such vessels, barge carriers (BA), dry cargo barges (BD), liquid barges (BL), supply vessels (SV) such as used for off-shore oil and gas production, and tugs (TUG) were not considered to have Category 3 engines onboard.

Table B-3. 1995 Detailed ports' Category 3 trips modified for unclassified vessels.

PORT NAME	BC	CS	GC	OT	PA	RF	RO	TA	UC	VC	Cat. 3 Total
Corpus Christi, TX	476	8	31	-	146	-	12	1,921	0	0	2,594
Tampa, FL	1,270	42	304	23	128	315	85	974	0	3	3,144

Table B-4. 1995 Matched ports' Category 3 trips modified for unclassified vessels.

PORT NAME	BC	CS	GC	OT	PA	RF	RO	TA	UC	VC	Cat. 3 Total
Beaumont, TX	108	8	18	-	3	3	33	719	-	-	892
Port Arthur, TX	438	33	172	27	14	3	22	1,220	-	-	1,929
Matagorda Ship Channel, TX	248	2	41	1	-	-	-	173	-	-	466
Brownsville, TX	505	125	104	34	8	-	26	88	9	9	898

The detailed port data may have fewer vessel types than were expected based on the USACE (2001) data, so all vessel types not explicitly categorized in the detailed data were assumed to be equivalent to the other or miscellaneous category. For Corpus Christi and the port matched to Corpus Christi (Beaumont), vessel trips associated with passenger (PA) and reefer (RF), roll on-roll off (RO), and vehicle carrier (VC) vessels were lumped with the other (OT) vessel types to conform to the detailed vessel data available for Corpus Christi. Detailed data for Tampa included all vessel types, so no adjustment was necessary for ports matched to Tampa. The results are shown in Tables B-5 and B-6.

Table B-5. 1995 detailed ports' Category 3 trips modified to match Marine Exchange vessel types.

PORT NAME	BC	CS	GC	OT	PA	RF	RO	TA	UC	VC	Cat. 3 Total
Corpus Christi, TX	476	8	31	158	-	-	-	1,921	0	-	2,594
Tampa, FL	1,270	42	304	23	128	315	85	974	0	3	3,144

Table B-6. 1995 matched ports' Category 3 trips modified to match Marine Exchange vessel types.

PORT NAME	BC	CS	GC	OT	PA	RF	RO	TA	UC	VC	Cat. 3 Total
Beaumont, TX	108	8	18	39	-	-	-	719	0	-	892
Port Arthur, TX	438	33	172	27	14	3	22	1,220	0	0	1,929
Matagorda Ship Channel, TX	248	2	41	1	0	0	0	173	0	0	466
Brownsville, TX	505	125	104	34	8	0	26	88	0	9	898

For the Texas ports, the ratio of the vessel trips by type of vessel were calculated and are shown in Table B-7 for the typical (or like) detailed ports of Corpus Christi and Tampa.

Table B-7. Ratio of the 1995 matched to the detailed ports' trips.

Like		BC	CS	GC	OT	PA	RF	RO	TA	VC
Port	Port									
CC	Beaumont, TX	0.23	1.03	0.57	0.25	-	-	-	0.37	-
TM	Port Arthur, TX	0.35	0.78	0.57	1.21	0.11	0.01	0.26	1.25	0.00
TM	Matagorda Ship Channel, TX	0.20	0.06	0.14	0.05	0.00	0.00	0.00	0.18	0.00
TM	Brownsville, TX	0.40	2.98	0.34	1.49	0.07	0.00	0.30	0.09	2.74

CC - Corpus Christi; TM - Tampa

For each port the RSZ speed and distance were needed to calculate the time and load in the RSZ mode, as summarized in Table B-8 based on discussions with the local pilots (Beaumont-Port Arthur, Brazos-Port Isabel, Matagorda Pilots (2001)). The speed was used to calculate the average load using the equation described below where the cruise speed was supplied by vessel type for each detailed port. The distance divided by the speed represents the time in mode for the RSZ mode.

$$\text{Load Factor} = 0.1 + 0.7 * (\text{Actual Speed} / \text{Cruise Speed})^3$$

Table B-8. Estimates of the Reduce Speed Zone (RSZ) trips by port.

Port	Distance	Speed (knots)
Corpus Christi, TX	25	10
Tampa, FL	24	9
Beaumont, TX	56.5	7
Port Arthur, TX	20	7
Matagorda Ship Channel, TX	24	7.25
Brownsville, TX	18.5	8.75

The emission estimates were then calculated by applying the vessel call ratio to the detailed port emission estimates by vessel type provided in Appendix A. RSZ mode emissions were adjusted for time and load in mode based on the specific conditions within each port and compared by ship type with the detailed port information shown in Table B-9.

Table B-9. Average vessel speed and Reduced Speed Zone load by ship type.

Ship Type	Corpus Christi		Tampa	
	Cruise Speed (knots)	RSZ Load	Cruise Speed (knots)	RSZ Load
Bulk Carrier	14.5	0.33	14.7	0.26
Container Ship	24.0	0.15	21.5	0.15
General Cargo	15.6	0.29	14.3	0.27
Passenger	-	-	19.7	0.17
Reefer	-	-	17.8	0.19
Roro	-	-	13.8	0.30
Tanker	15.1	0.30	15.0	0.25
Vehicles Carrier	-	-	18.0	0.19
Miscellaneous	12.5	0.46	13.0	0.33

The emission totals are provided below and reflect the 1996 emission estimates because the Marine Exchange data for the detailed ports was based on 1996 activity. The 1995 vessel trip data was used to determine the relative activity between ports and applied to the 1996 activity data.

1996 Corpus Christi Emission Totals (Tons/year)

Vessel Type	HC	CO	NO _x	PM	SO ₂
BULK CARRIER Total	7	37	385	22	152
CONTAINER SHIP Total	0	1	7	0	2
TANKER Total	28	126	1426	182	1109
GENERAL CARGO Total	0	1	10	1	5
MISCELLANEOUS Total	0	0	3	0	1
TOTAL	35	165	1831	205	1270
<i>Transit</i>	<i>29</i>	<i>63</i>	<i>1260</i>	<i>154</i>	<i>1179</i>
<i>Hotelling</i>	<i>6</i>	<i>102</i>	<i>570</i>	<i>51</i>	<i>91</i>

1996 Beaumont Emission Totals (Tons/year)

Vessel Type	HC	CO	NO _x	PM	SO ₂
BULK CARRIER Total	2	9	101	6	42
CONTAINER SHIP Total	0	1	9	0	3
TANKER Total	13	52	629	81	616
GENERAL CARGO Total	0	1	7	1	4
MISCELLANEOUS Total	0	0	1	0	0
TOTAL	15	63	746	88	666
<i>Transit</i>	<i>13</i>	<i>27</i>	<i>550</i>	<i>69</i>	<i>531</i>
<i>Hotelling</i>	<i>2</i>	<i>35</i>	<i>196</i>	<i>19</i>	<i>135</i>

1996 Tampa Emission Totals (Tons/year)

Vessel Type	HC	CO	NO _x	PM	SO ₂
BULK CARRIER Total	16	113	970	50	339
CONTAINER SHIP Total	0	3	23	1	5
GENERAL CARGO Total	4	25	220	13	90
PASSENGER Total	6	30	311	18	125
REEFER Total	1	10	74	3	21
RORO Total	0	3	25	1	7
TANKER Total	8	33	370	49	376
VEHICLES CARRIER Total	0	1	7	0	1
MISCELLANEOUS Total	0	6	36	1	6
Total	36	225	2036	137	971
<i>Transit</i>	26	51	1090	99	746
<i>Hotelling</i>	10	174	946	38	225

1996 Port Arthur Emission Totals (Tons/year)

Vessel Type	HC	CO	NO _x	PM	SO ₂
BULK CARRIER Total	5	38	319	16	108
CONTAINER SHIP Total	0	3	18	1	4
GENERAL CARGO Total	2	14	117	7	46
PASSENGER Total	1	3	32	2	12
REEFER Total	0	0	1	0	0
RORO Total	0	1	6	0	2
TANKER Total	9	40	433	58	441
VEHICLES CARRIER Total	0	0	0	0	0
MISCELLANEOUS Total	1	7	43	1	7
Total	17	107	969	85	620
<i>Transit</i>	13	25	520	56	425
<i>Hotelling</i>	5	82	449	29	195

1996 Matagorda Ship Channel Emission Totals (Tons/year)

Vessel Type	HC	CO	NO _x	PM	SO ₂
BULK CARRIER Total	3	22	185	10	64
CONTAINER SHIP Total	0	0	1	0	0
GENERAL CARGO Total	1	3	29	2	11
PASSENGER Total	0	0	0	0	0
REEFER Total	0	0	0	0	0
RORO Total	0	0	0	0	0
TANKER Total	1	6	64	8	65
VEHICLES CARRIER Total	0	0	0	0	0
MISCELLANEOUS Total	0	0	2	0	0
Total	5	31	281	20	141
<i>Transit</i>	4	7	147	14	105
<i>Hotelling</i>	1	25	134	6	36

1996 Brownsville Emission Totals (Tons/year)

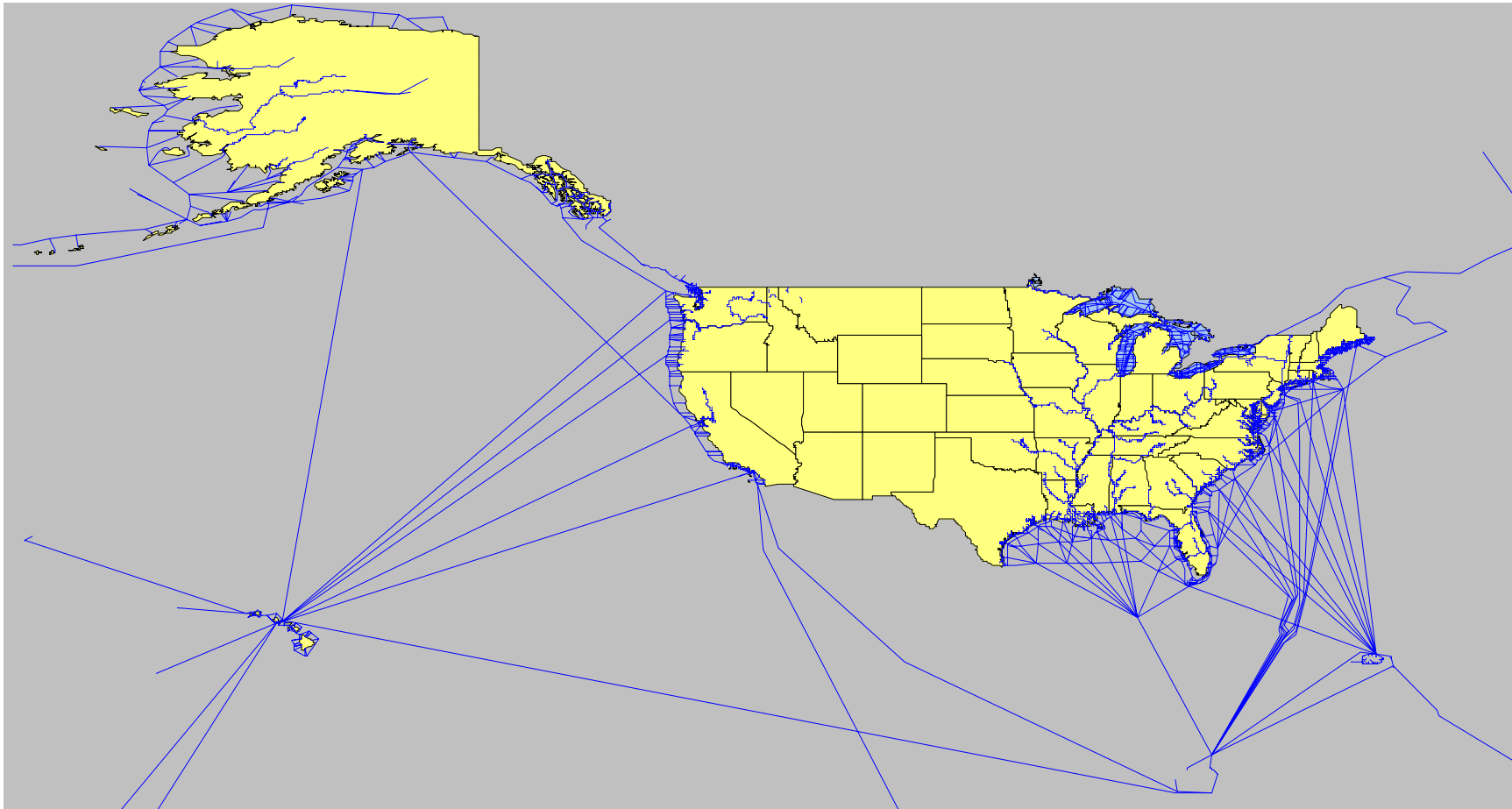
Vessel Type	HC	CO	NO_x	PM	SO₂
BULK CARRIER Total	6	44	370	19	125
CONTAINER SHIP Total	1	10	69	3	15
GENERAL CARGO Total	1	8	71	4	28
PASSENGER Total	0	2	19	1	7
REEFER Total	0	0	0	0	0
RORO Total	0	1	7	0	2
TANKER Total	1	3	31	4	32
VEHICLES CARRIER Total	0	3	18	1	4
MISCELLANEOUS Total	1	9	53	2	8
Total	10	80	638	33	222
<i>Transit</i>	7	12	271	23	169
<i>Hotelling</i>	4	68	367	10	53

APPENDIX C

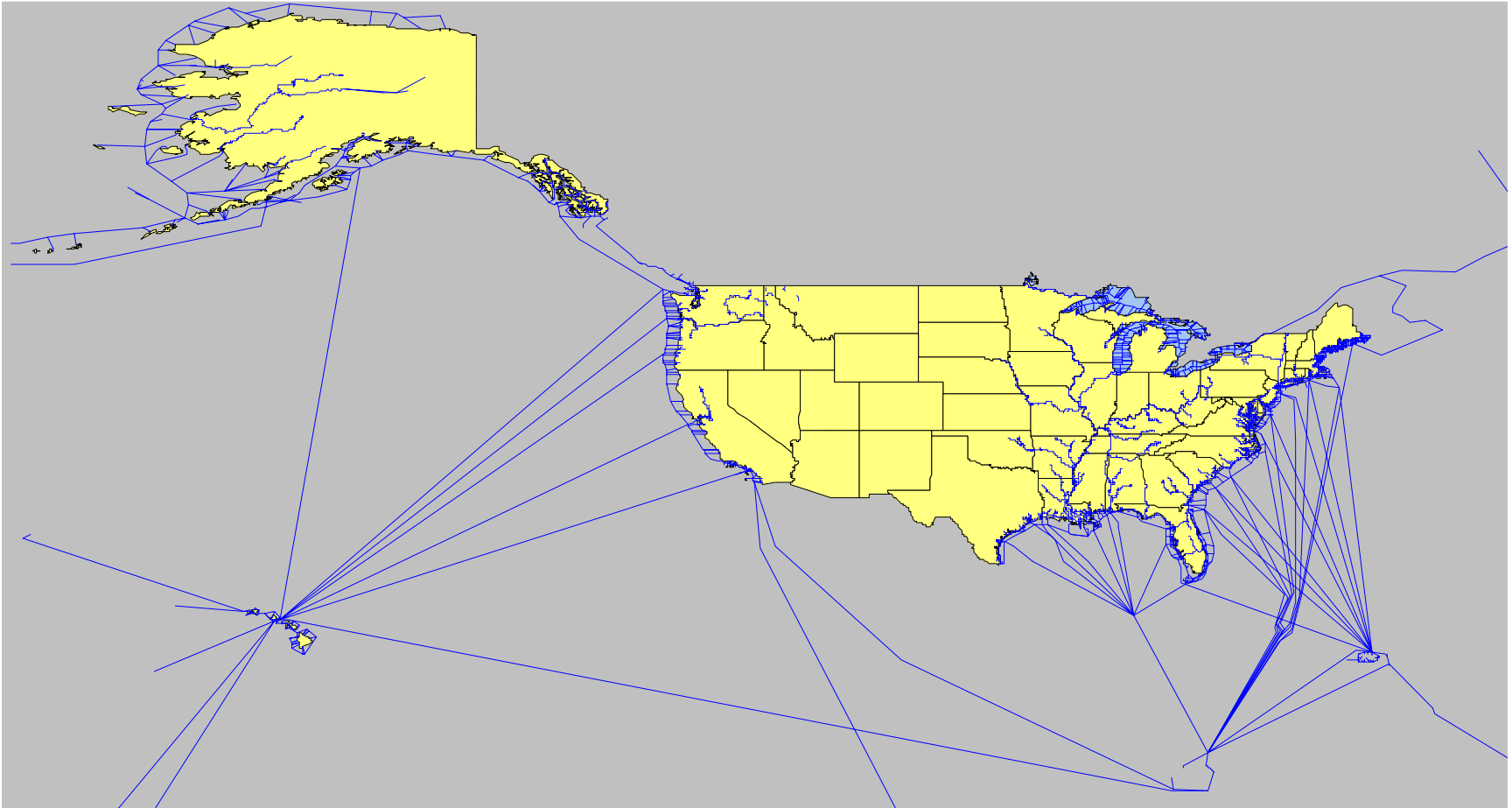
Maps USACE Waterway Link Network

MAPS USACE WATERWAY LINK NETWORK

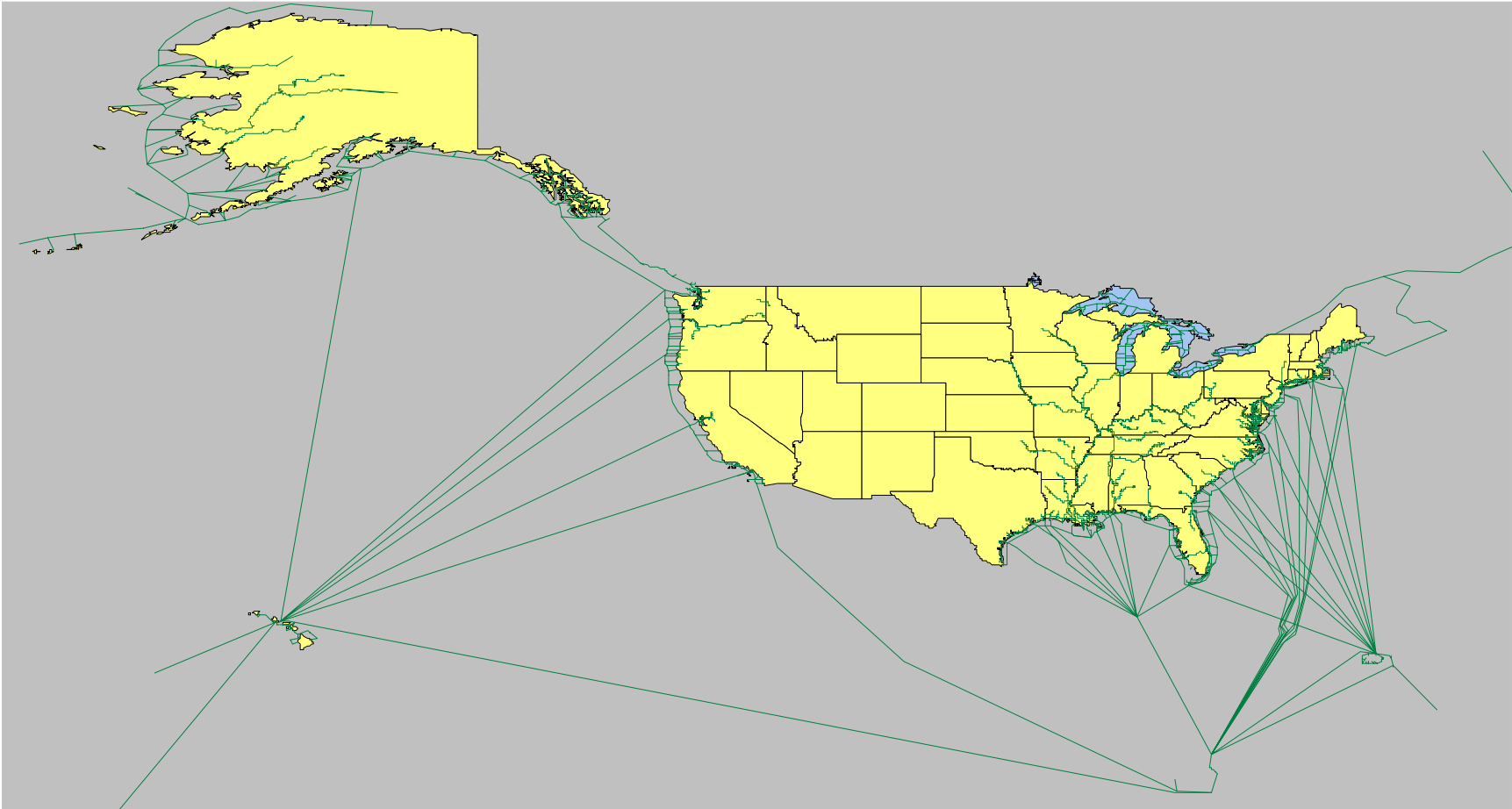
National Waterway Network (NWN)



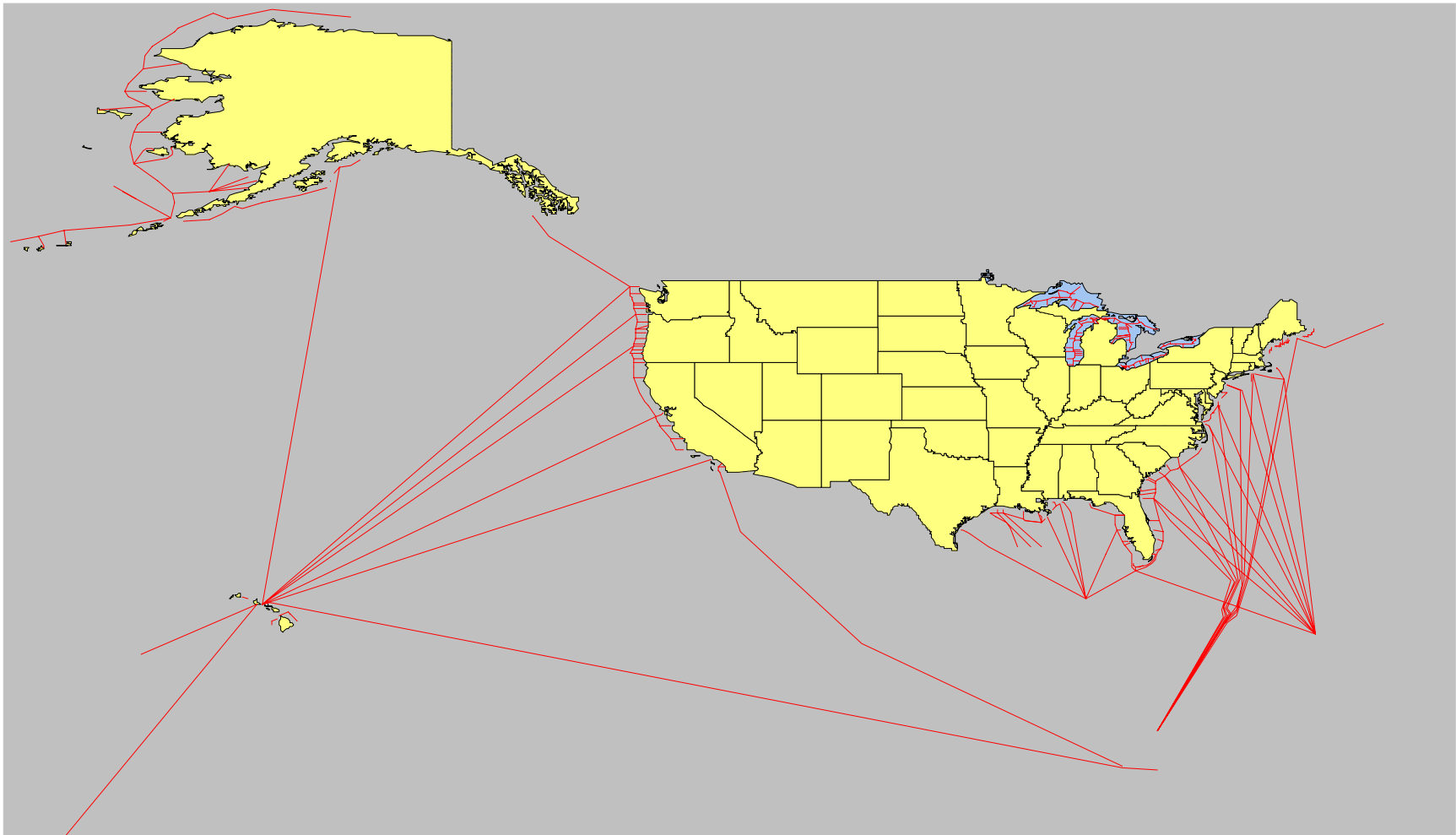
USACE Waterway Link Network



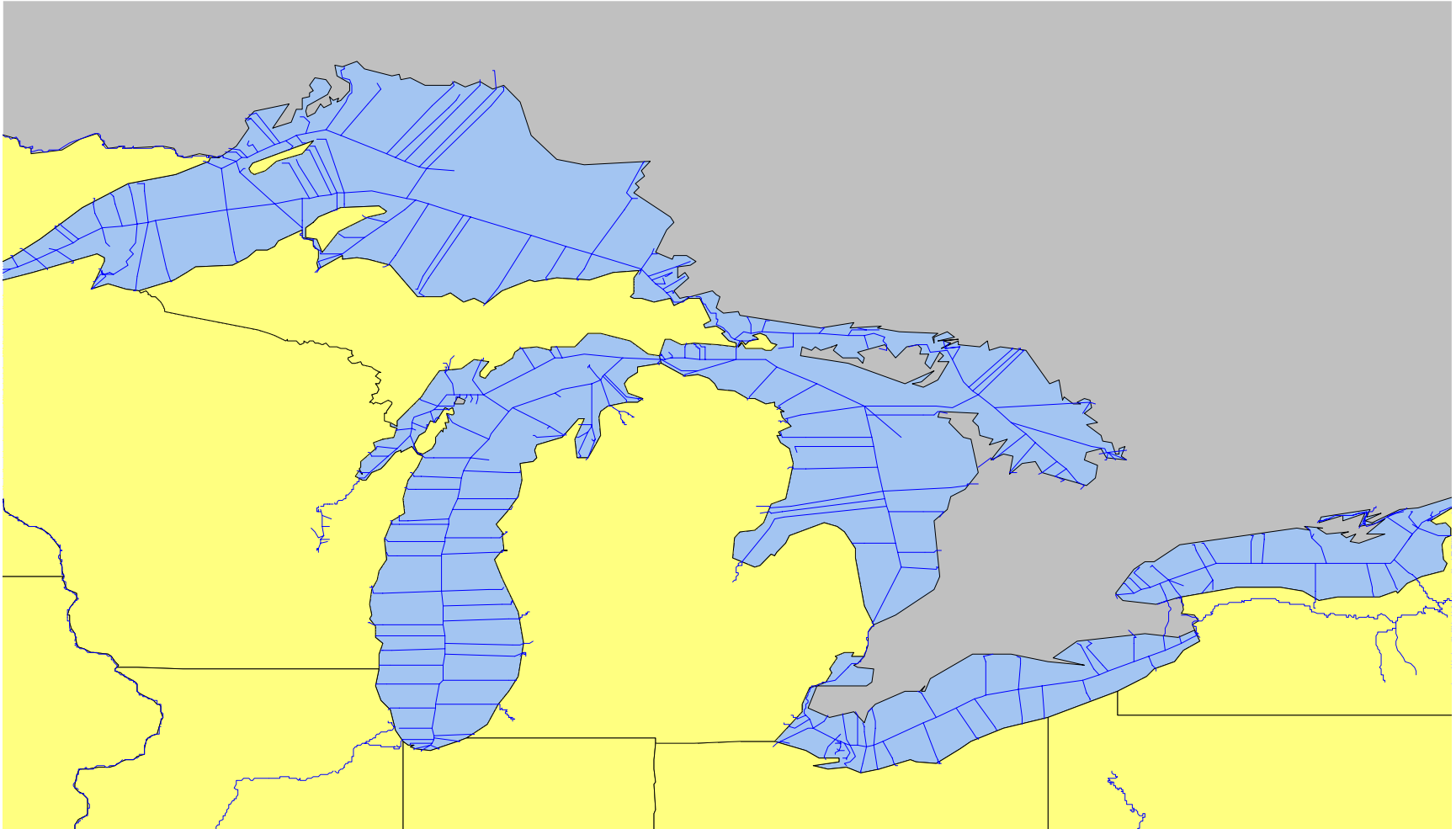
USACE Waterway Link Network – Links with 1999 Commodity Tonnage Data



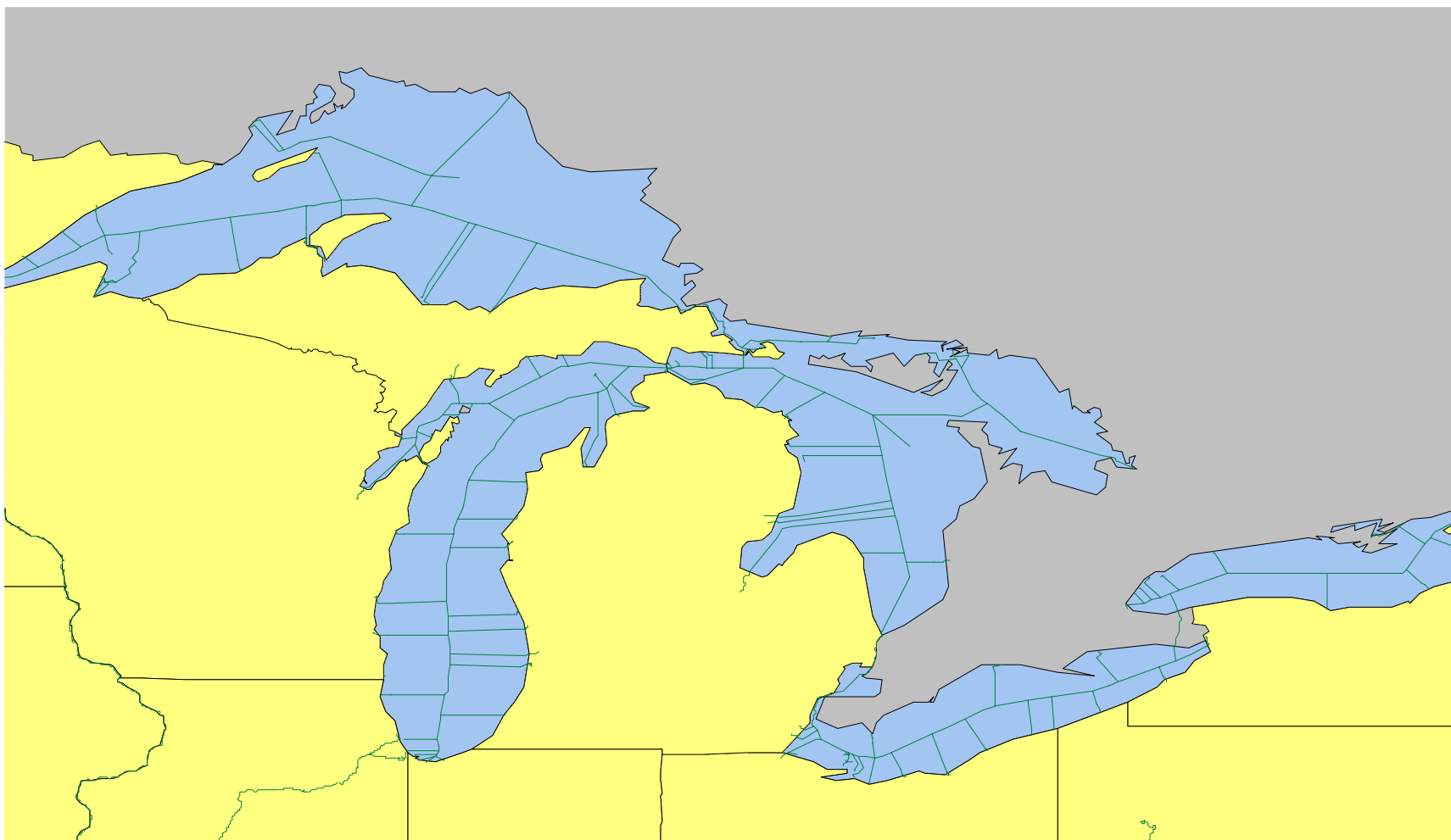
USACE Waterway Link Network – Links with 1999 Commodity Tonnage Data Classified as Offshore (>25mi from shore for ocean-going, >10mi from shore for Great Lakes)



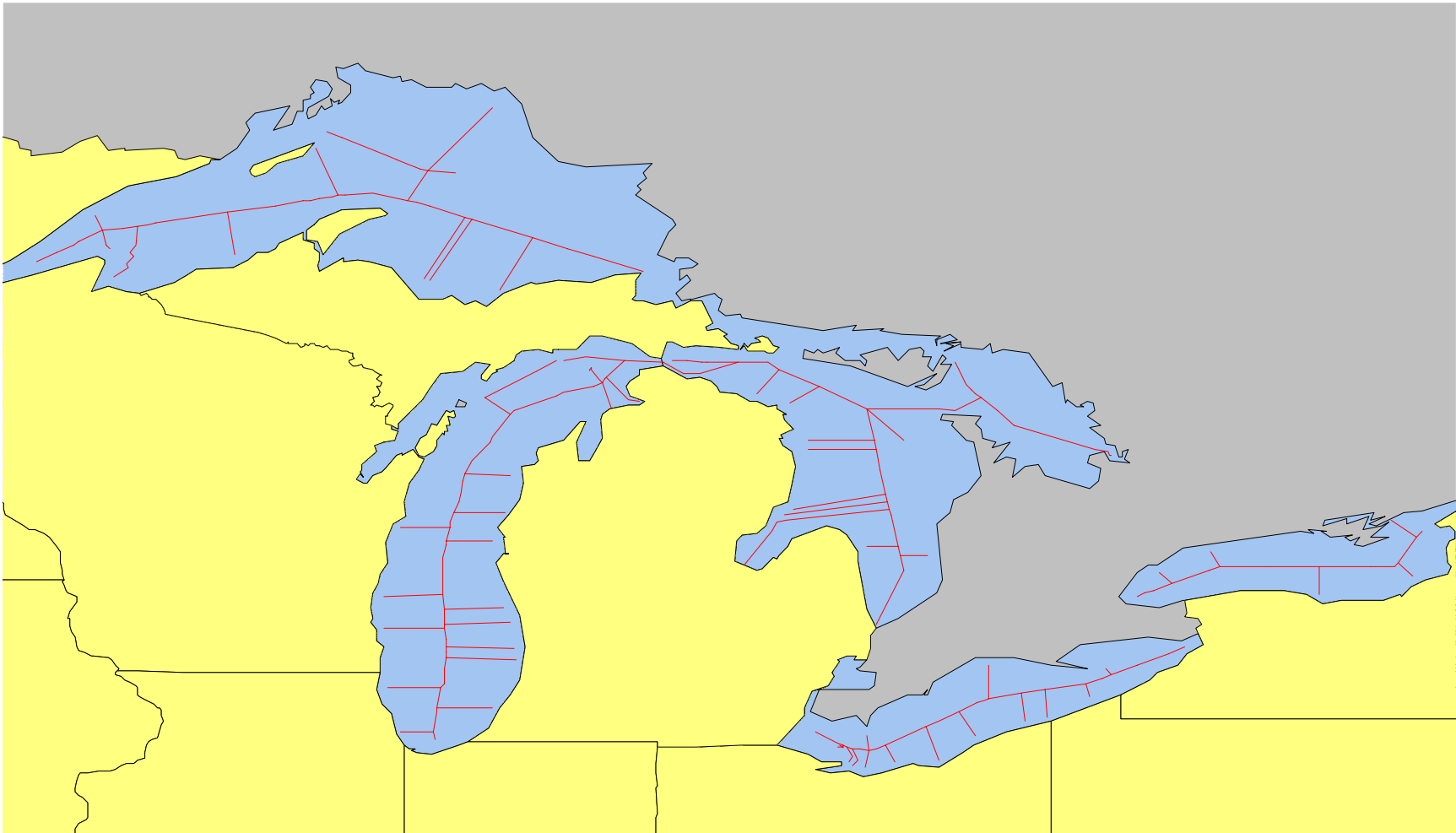
USACE Waterway Link Network (Great Lakes)



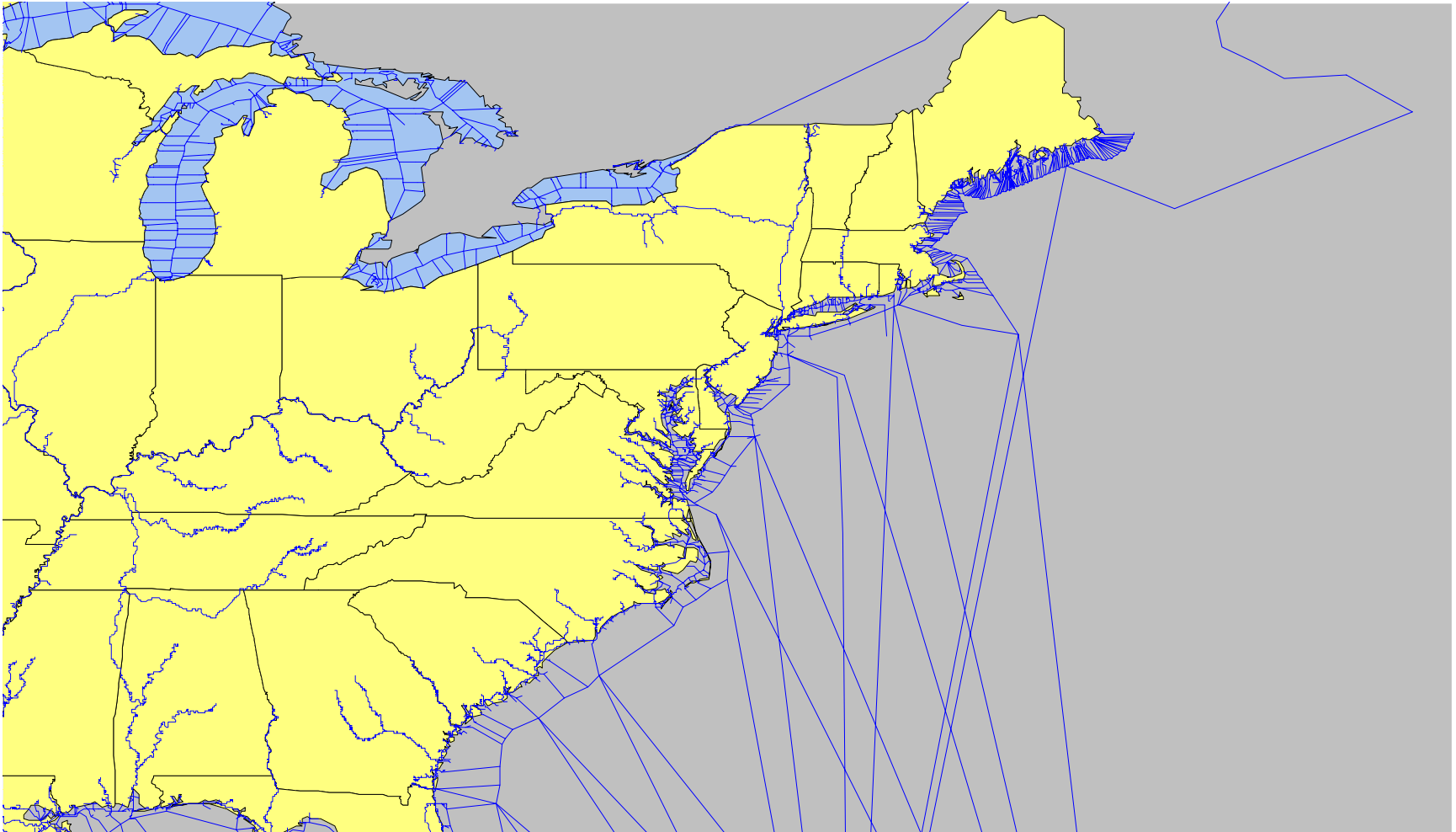
USACE Waterway Link Network – Links with 1999 Commodity Tonnage Data (Great Lakes)



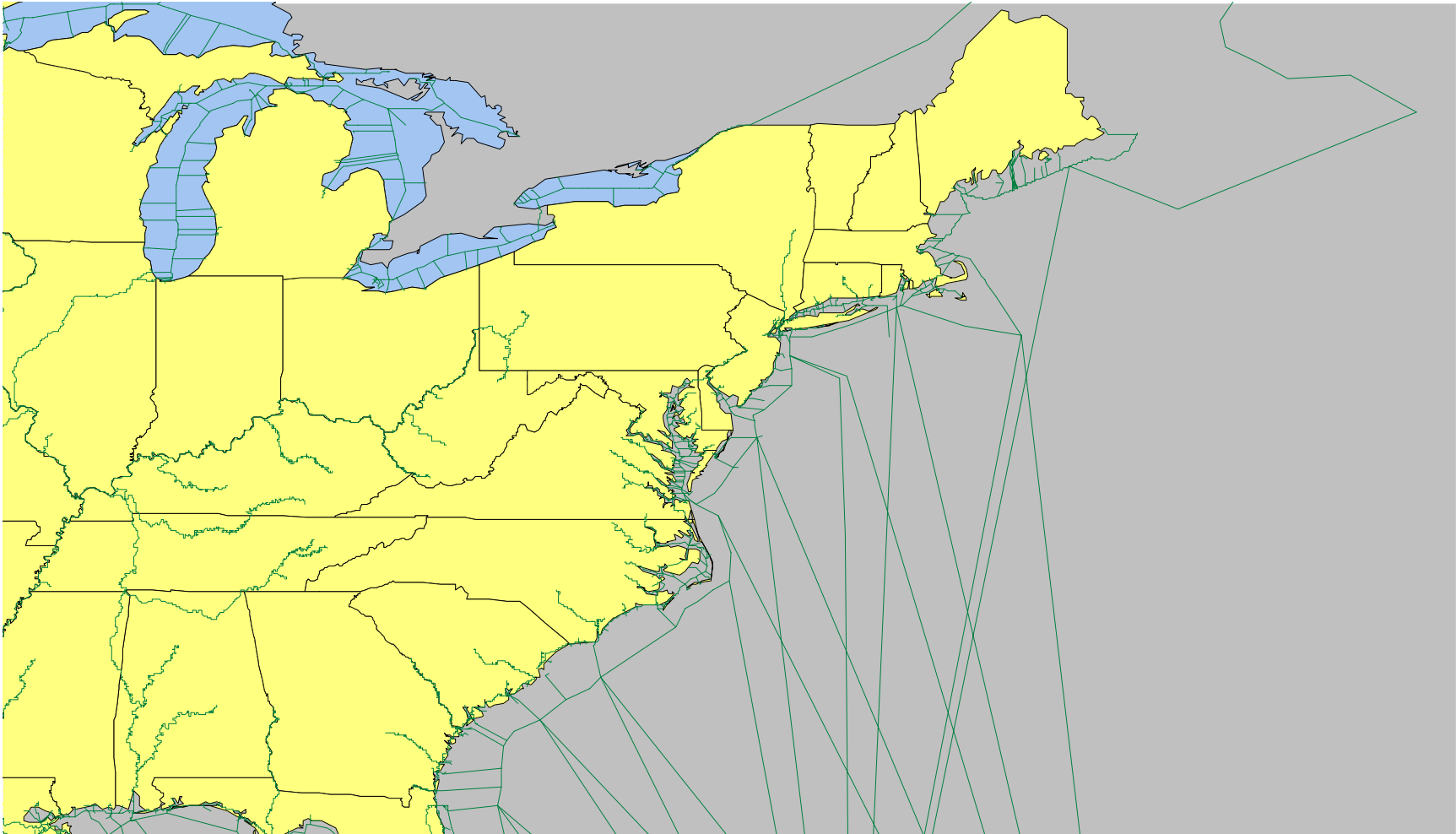
USACE Waterway Link Network – Links with 1999 Commodity Tonnage Data Classified as Offshore (>10mi from shore for Great Lakes)



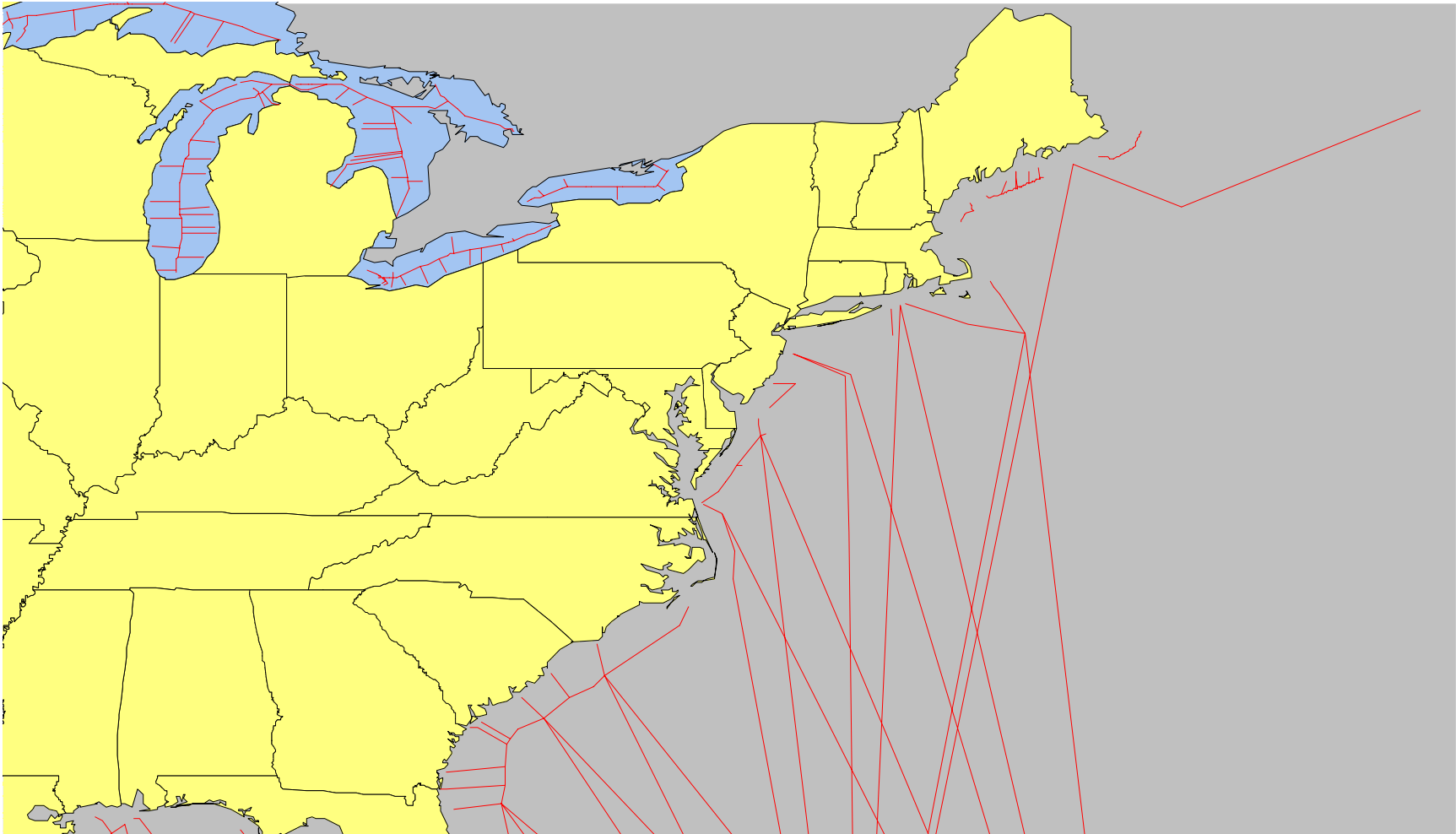
USACE Waterway Link Network (East Coast)



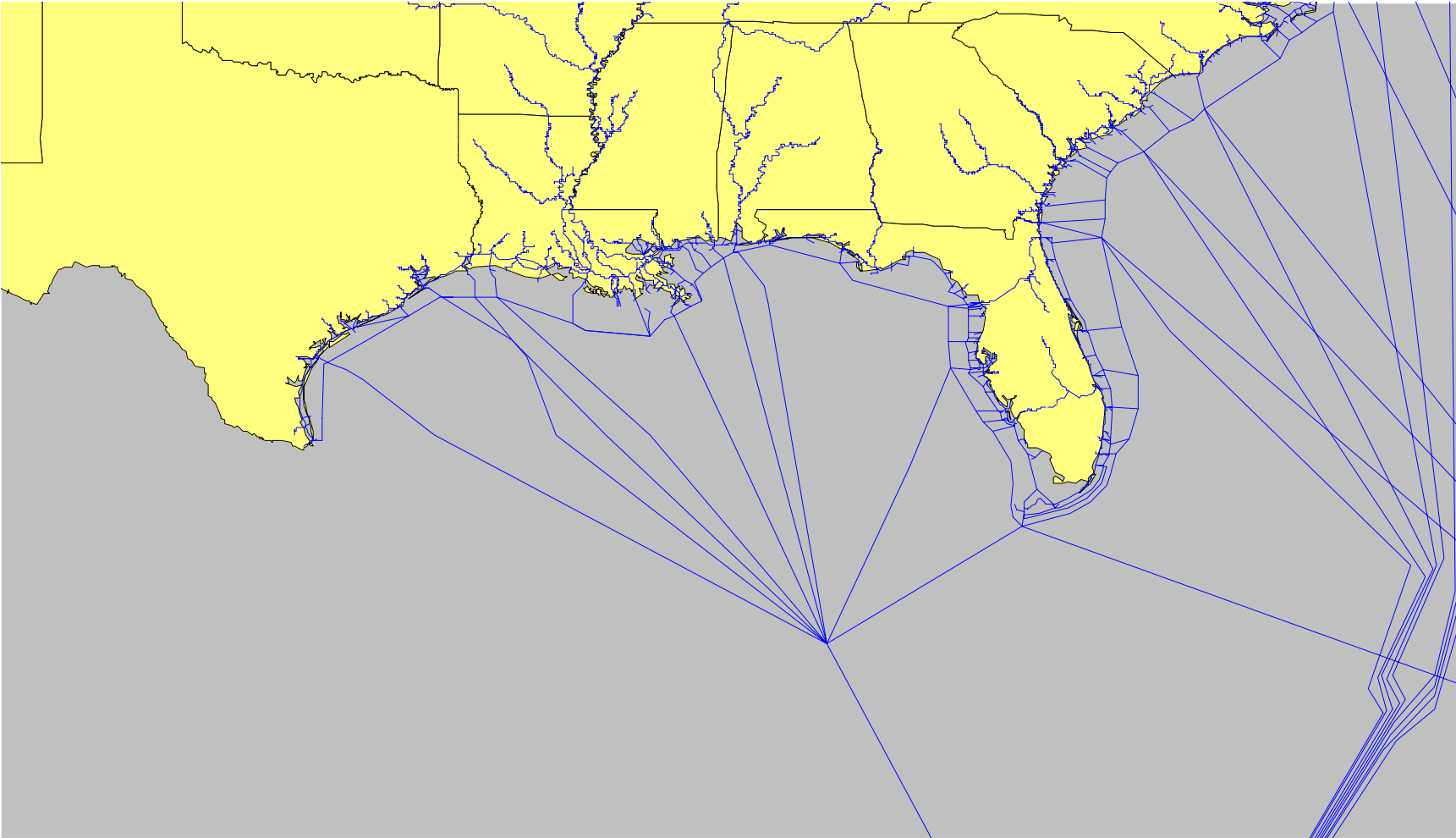
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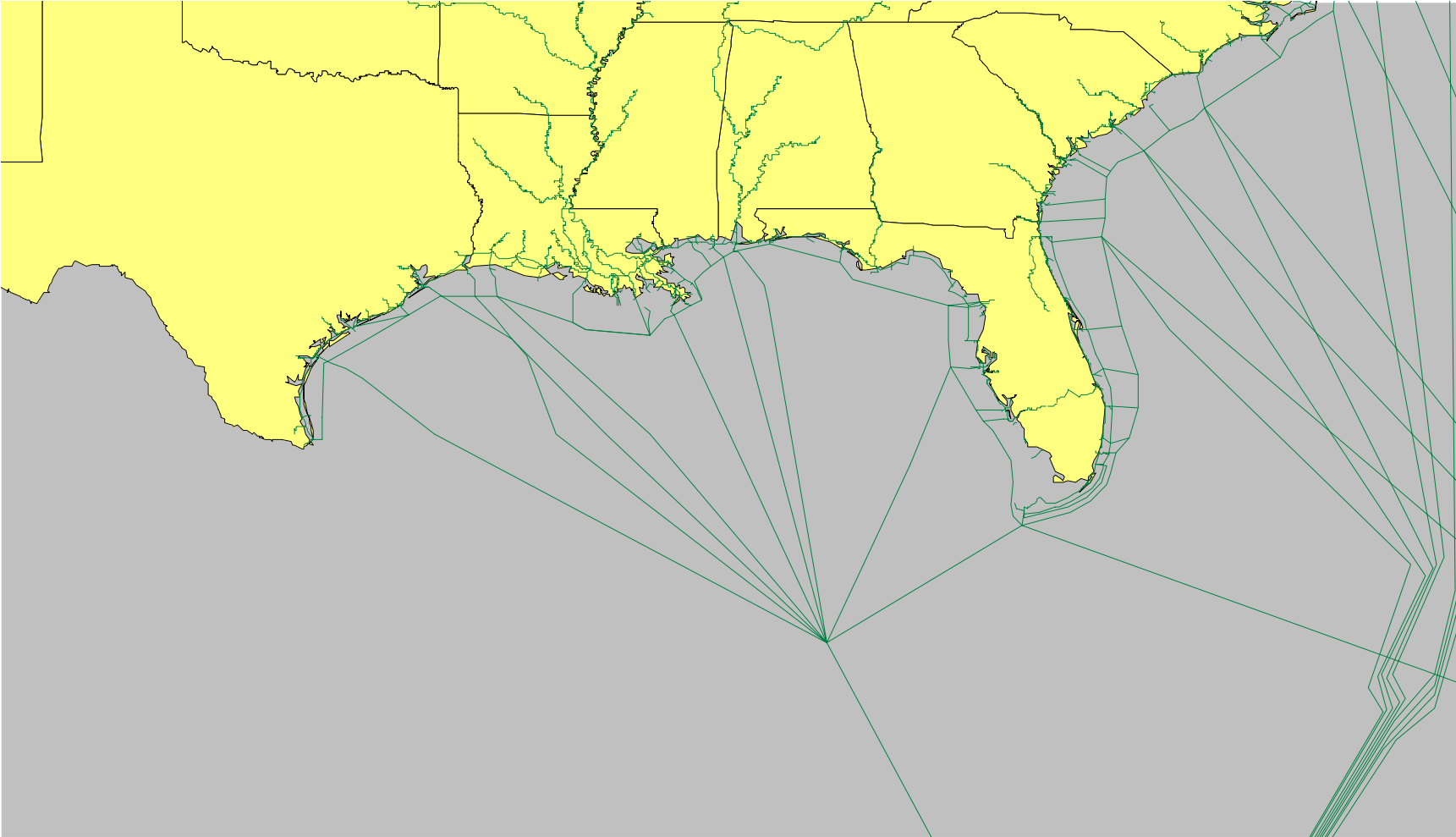
USACE Waterway Link Network – Links with 1999 Commodity Tonnage Data Classified as Offshore (>25mi from shore for East Coast)



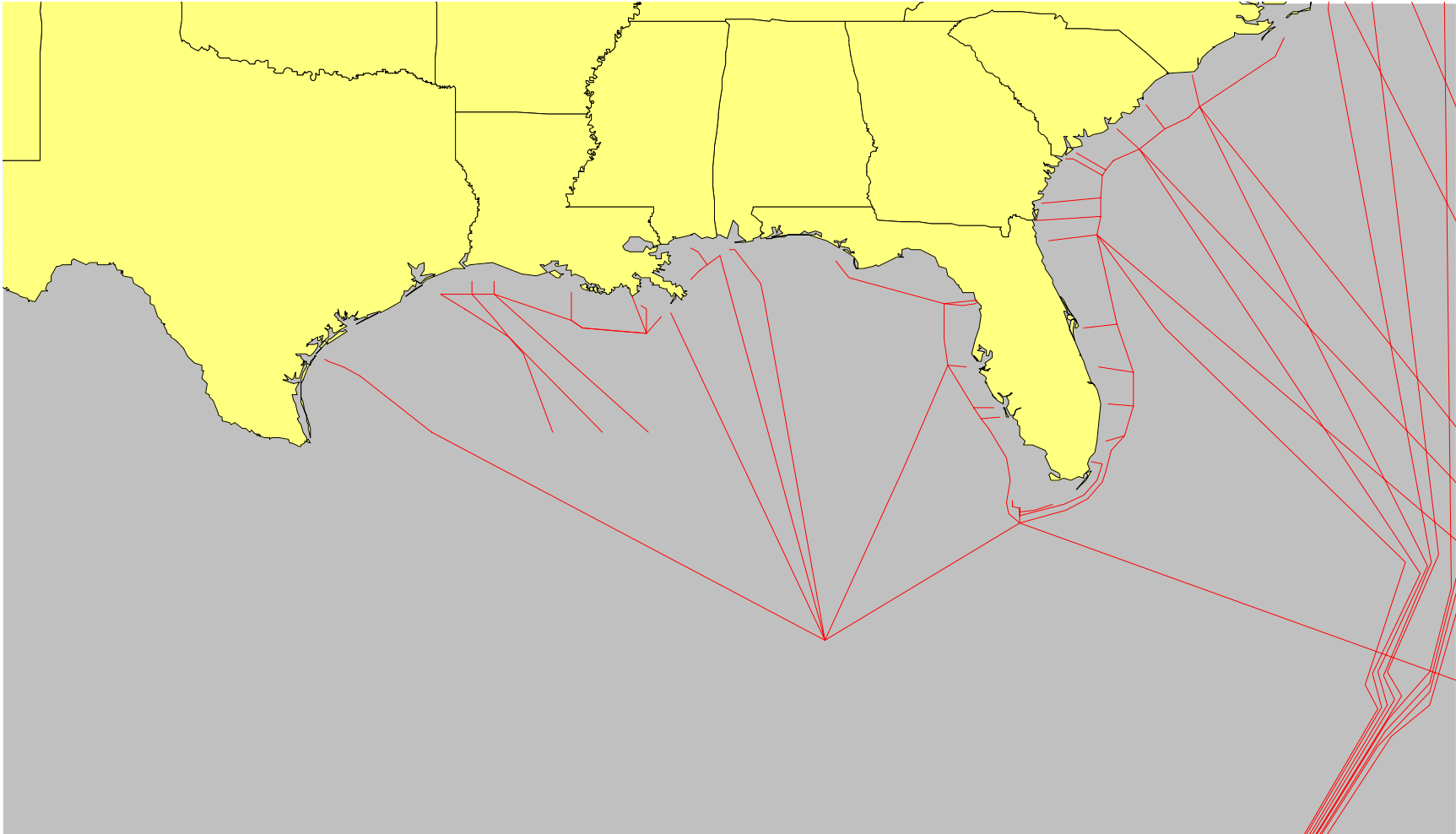
USACE Waterway Link Network (Gulf Coast)



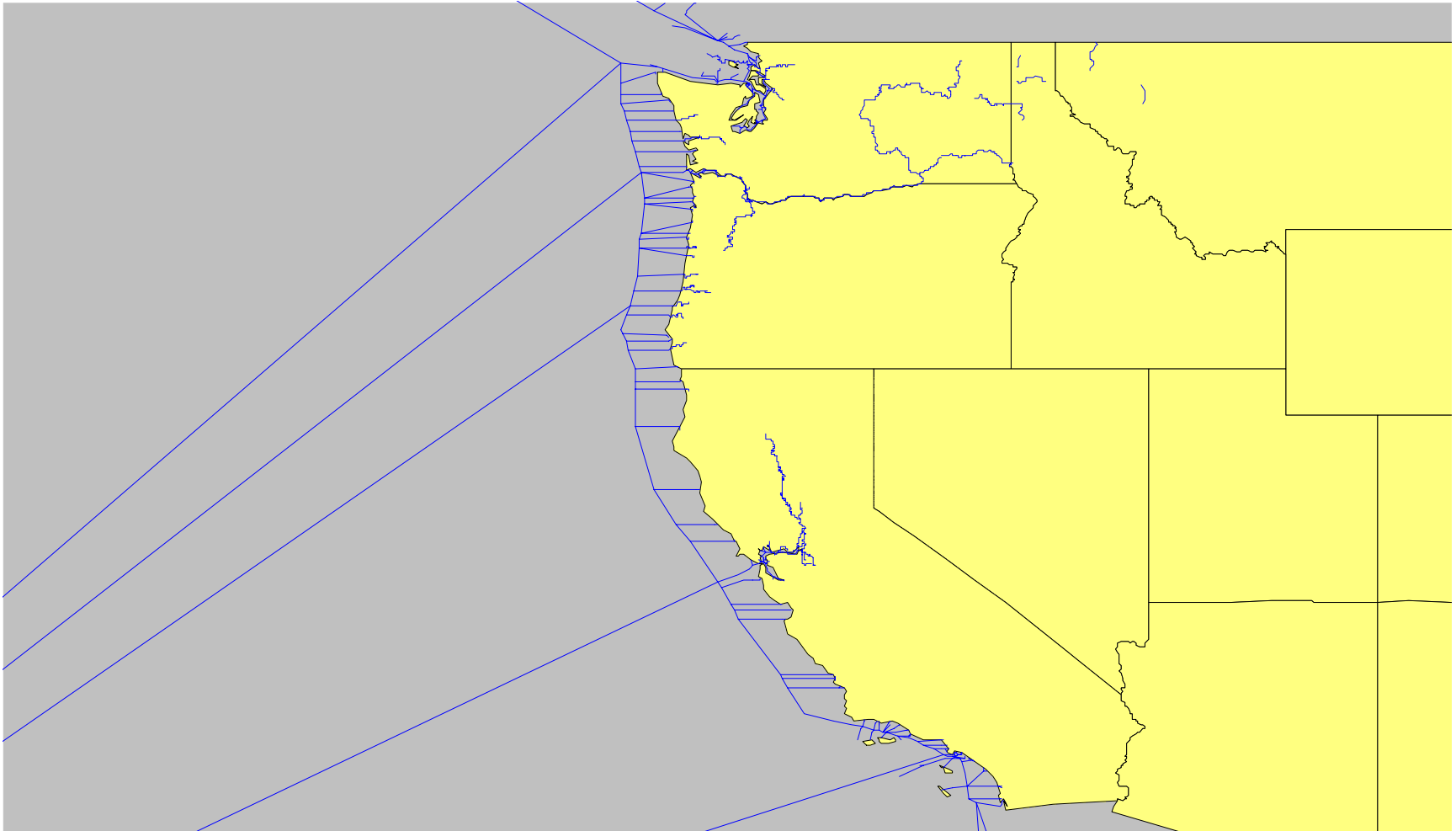
USACE Waterway Link Network – Links with 1999 Commodity Tonnage Data (Gulf Coast)



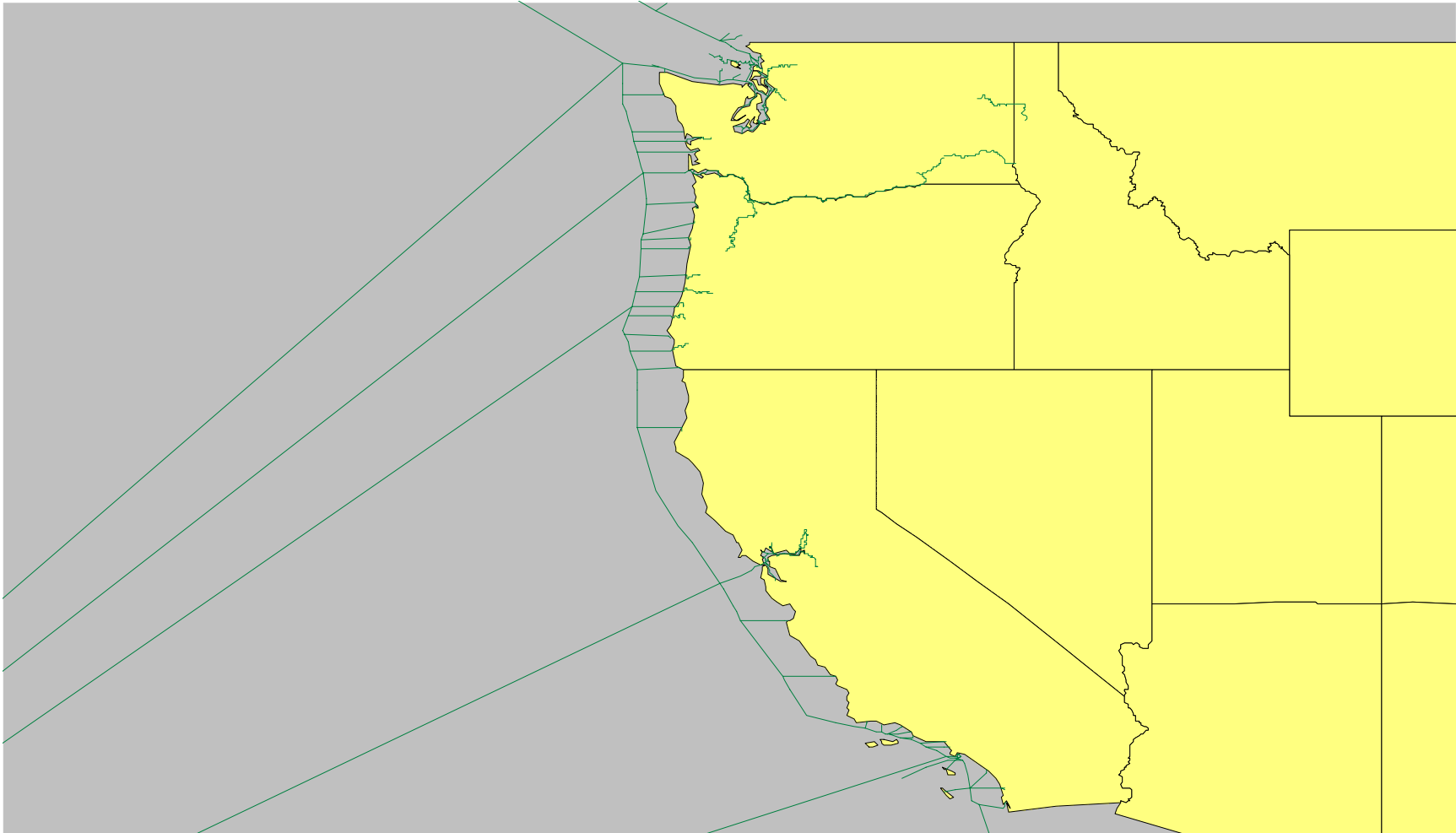
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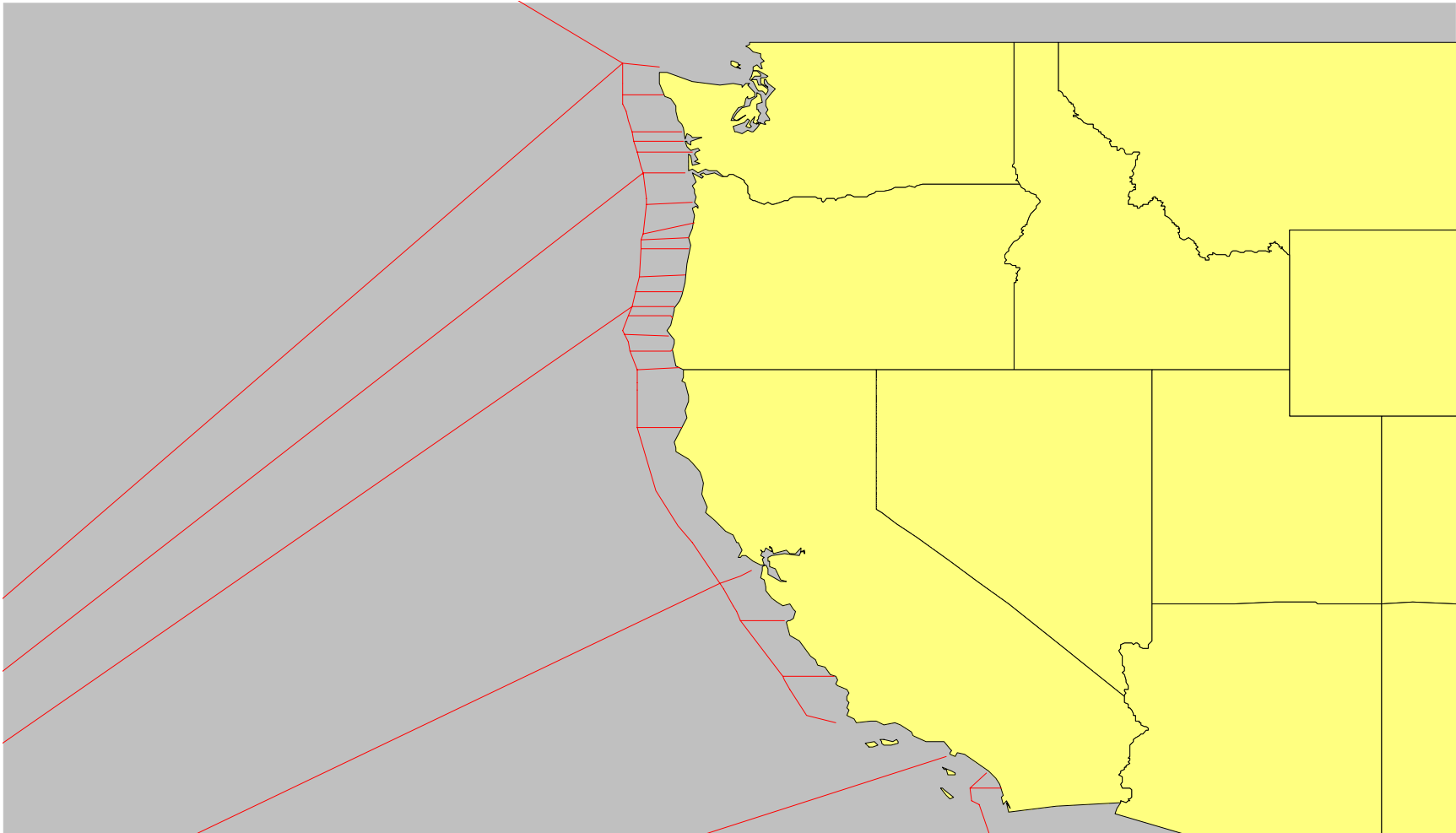
USACE Waterway Link Network (West Coast)



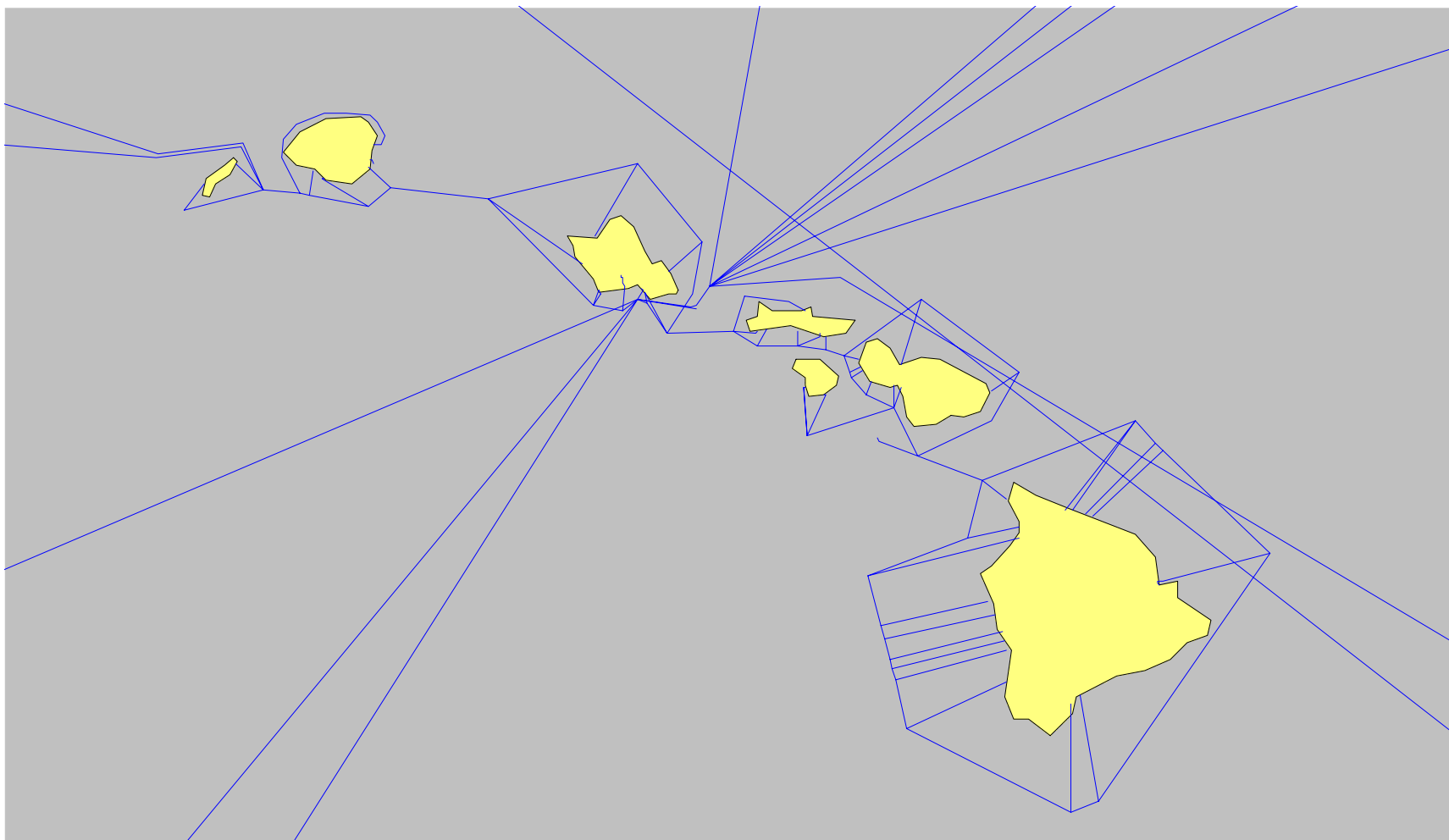
USACE Waterway Link Network – Links with 1999 Commodity Tonnage Data (West Coast)



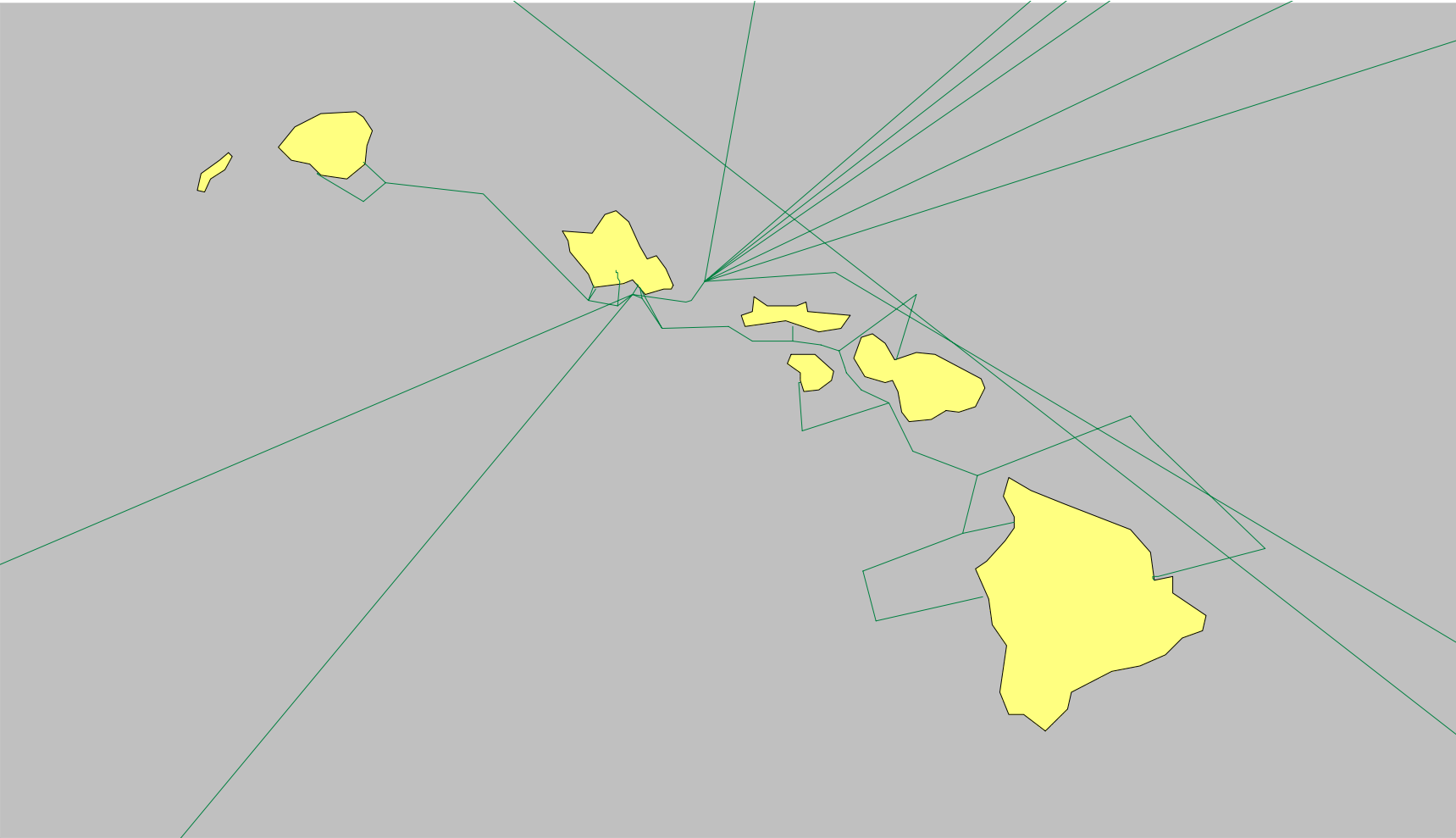
USACE Waterway Link Network – Links with 1999 Commodity Tonnage Data Classified as Offshore (>25mi from shore for West Coast)



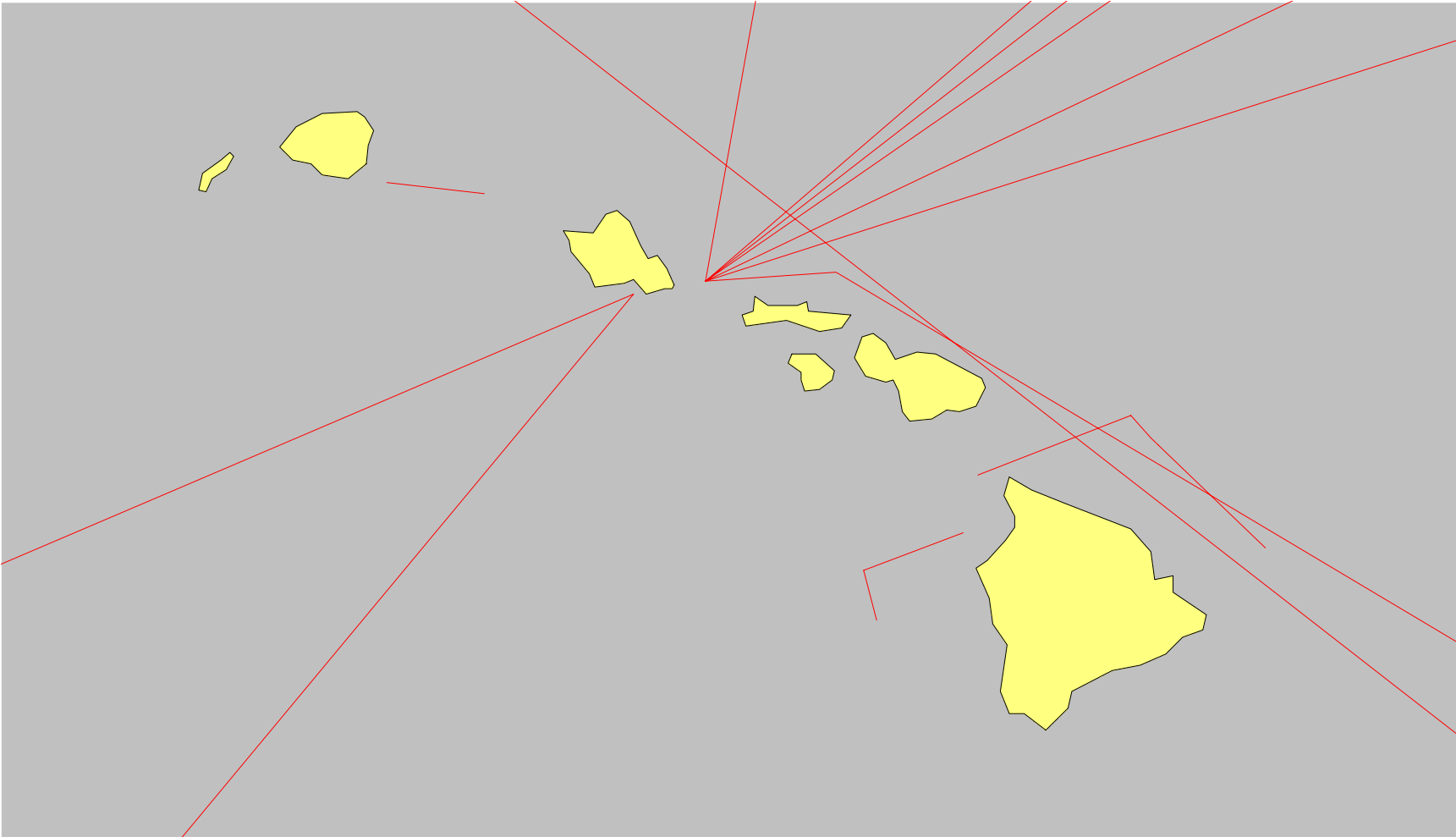
USACE Waterway Link Network (Hawaii)



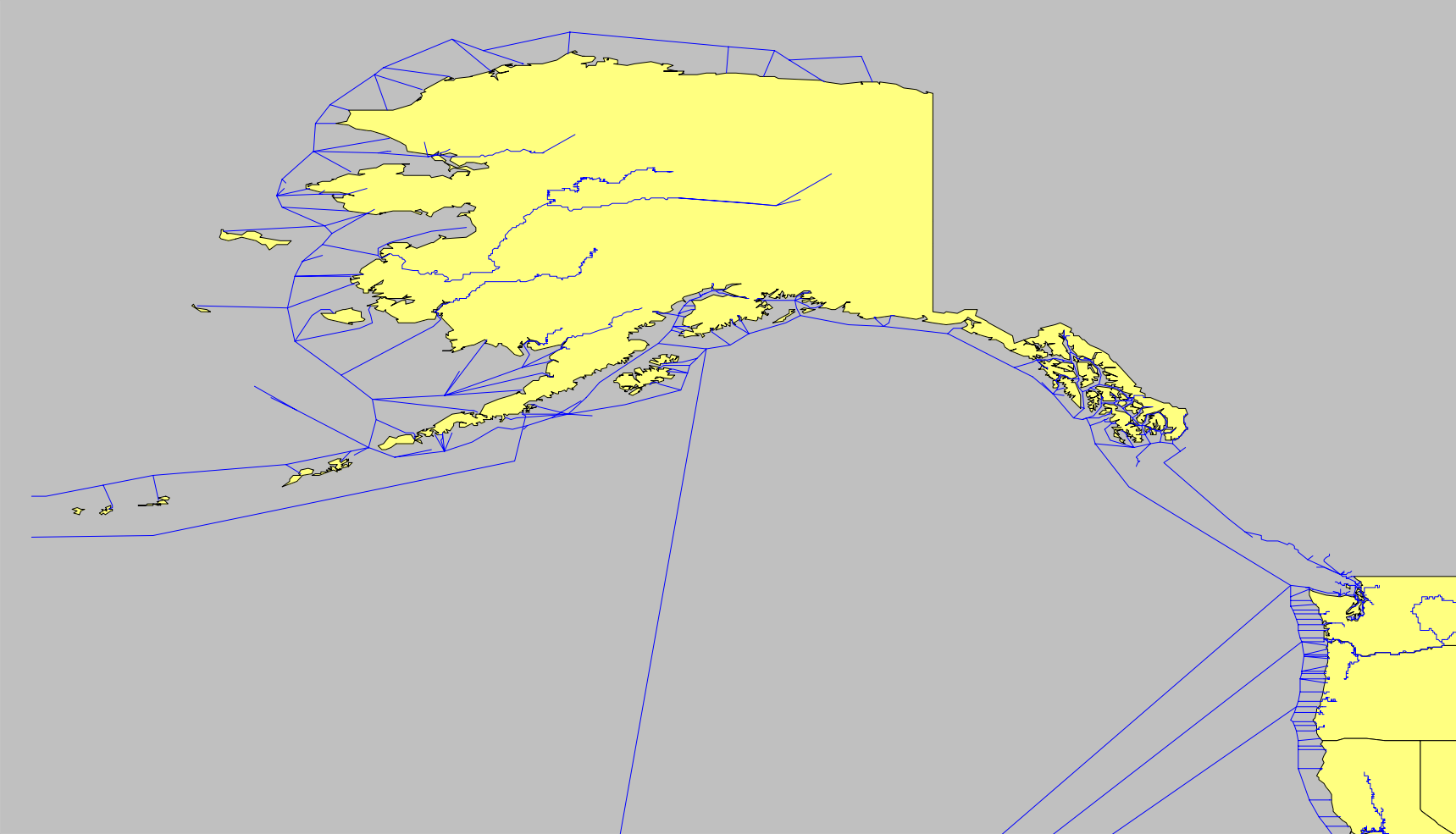
USACE Waterway Link Network – Links with 1999 Commodity Tonnage Data (Hawaii)



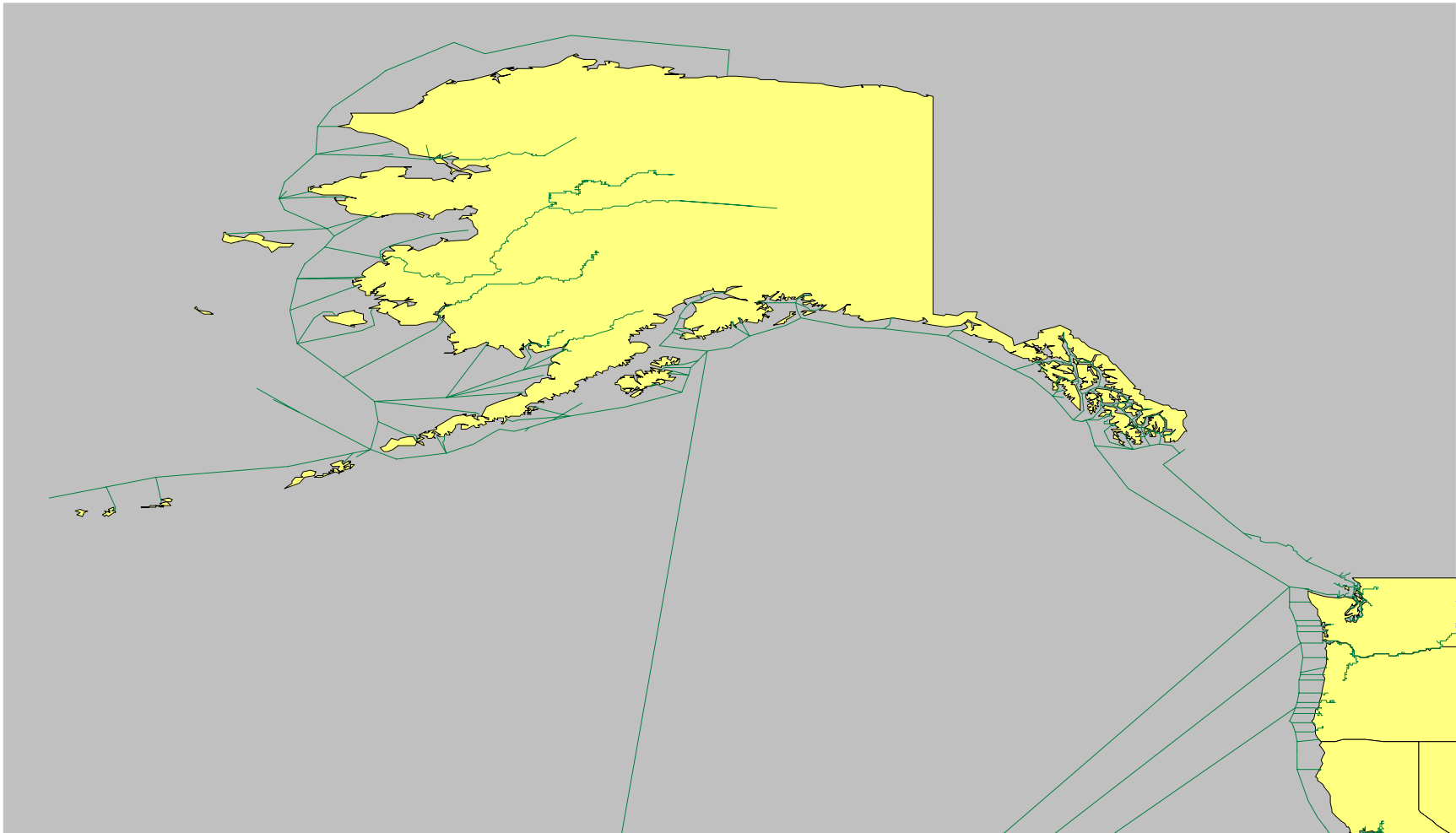
USACE Waterway Link Network – Links with 1999 Commodity Tonnage Data Classified as Offshore (>25mi from shore for Hawaii)



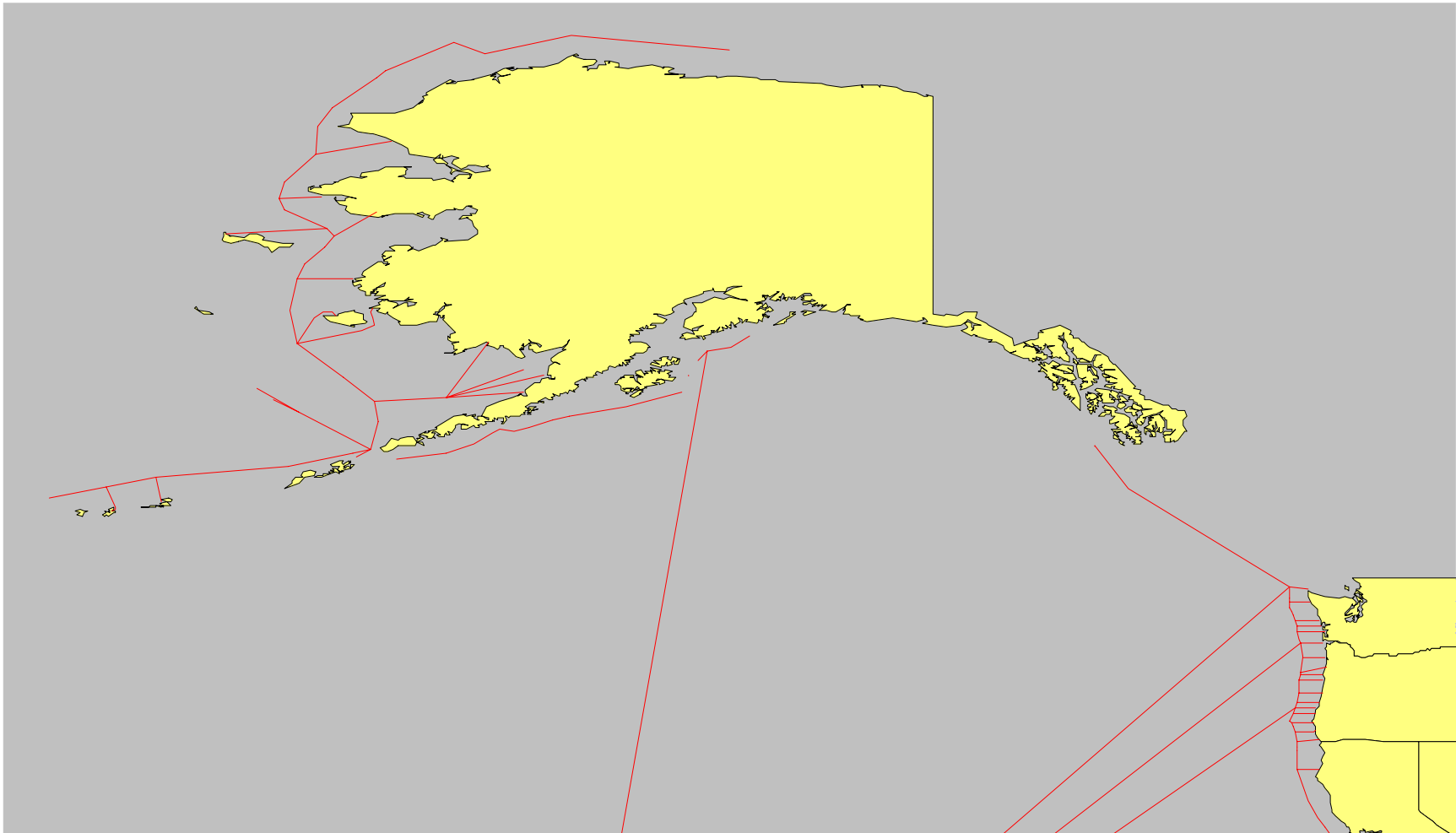
USACE Waterway Link Network (Alaska)



USACE Waterway Link Network – Links with 1999 Commodity Tonnage Data (Alaska)



USACE Waterway Link Network – Links with 1999 Commodity Tonnage Data Classified as Offshore (>25mi from shore for Alaska)



APPENDIX D

Domestic Fleet Traffic

DOMESTIC FLEET TRAFFIC

The difficulty with the domestic fleet was that some of the ocean and lake traffic could be served by either tow boats (using Category 1 or 2 engines) or larger vessels (using Category 3 engines). The domestic fleet comprises a relatively small number of vessels from the BTS (1999) review quoted below.

“The fleet serving U.S. domestic deep-sea trades in 1997 included 39 dry-cargo vessels (800,000 dwt), 122 tankers (8.2 million dwt), 3,393 dry-cargo barges (4.8 million DWT) and 669 tank barges (3.4 million dwt). Barges carried 86 percent of deep-sea cargoes moved less than 500 miles, while self-propelled vessels carried 91 percent of the metric tons moved in trades greater than 1,500 miles.”

The Table C-1 describes the domestic sea trade tonnage by length of voyage demonstrating that most of the traffic traveling over 1,000 miles was handled by vessels, considered in this work to be powered by Category 3 propulsion engines. Applying the average trip length to the tonnage by vessel from Table D-1 indicates that domestic ton-miles would be estimated to be 223×10^9 for all traffic compared with the 112×10^9 estimate in this work for ocean trip traffic in the 25 - 200 mile range.

Table D-1. Domestic Deep-Sea Trade, Self-Propelled Vessel v. Barge, by Length of Haul, 1997 (Million metric tons) (Table 1-18, BTS, 1999)

Miles	Barge	Vessel	Total	Percent (barge)
< 500	55.6	9.2	64.8	85.8
500-1,000	32.7	12	44.7	73.1
1,001-1,500	11.7	42	53.7	21.8
1,501-2,000	3.7	35.3	39	9.4
> 2,000	3.6	38.4	42	8.6
Total	107.3	137	244.3	43.9

APPENDIX E

Comparison with Corbett and Fischbeck (1998)

EMISSION TOTAL COMPARISONS

A comparison of the emission results from this work with those previously estimated for Corbett and Fischbeck (1998). The comparison shows that the emission totals are similar for all vessels together though somewhat smaller for the comparable in-use year of 1996.

Table E-1. Comparison of Category 3 results between Corbett and Fischbeck (1998). (1,000 tons/year).

Emission Estimate	HC	CO	NO_x	PM	SO₂
Corbett (1998) (Table 2) 1996 Category 3 US Flag	3.4	10.6	118.8	9.6	-
Corbett (1998) (Table 2) 1996 Category 3 Foreign Flag	3.6	11.0	116.9	8.7	-
Corbett (1998) (Table 2) 1996 Category 3 Total	7.0	21.6	235.7	18.3	-
Corbett (1998) (Table 3) 1993 Category 3 US Flag	1.3	4.4	57.1	4.1	-
Corbett (1998) (Table 3) 1993 Category 3 Foreign Flag	3.6	11.0	117.0	8.7	-
Corbett (1998) (Table 3) 1993 Category 3 Total	4.9	15.4	174.0	12.8	-
Chapter 3 Category 3* 1996 Near Ports	5.2	11.5	101.0	9.2	68.2
Chapter 4 Category 3* 1996 Between Ports	2.1	4.2	88.8	7.8	58.9
1996 Total Emissions	7.3	15.7	189.8	17.0	127.1

* Category 3 were summed as transit mode emissions of merchant vessels plus hotelling emissions for passenger and reefer vessels including steamships.